

THE UNIVERSITY OF CHICAGO

A NEW TECHNIQUE OF FIELD CROP LABOR ANALYSIS

A PART OF A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE SOCIAL SCIENCES IN
CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Department of Economics

1946

BY

RAYMOND TERRY BURDICK

Technical Bulletin 36
Colorado Agricultural Experiment Station
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COLORADO AGRICULTURAL EXPERIMENT STATION

COLORADO A & M COLLEGE

Fort Collins

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ILLUSTRATION OF USE OF EQUATIONS DEVELOPED IN THIS REPORT

Those who wish to try this technique of field crop labor analysis without taking time to follow the complete report will find that the key to the analysis is contained in the equation

$$T = \frac{8.25}{SW} \left(1 + \frac{16 SN}{3 L} \right) (1 + A).$$

In this equation T is the crew hours per acre per operation for once over. S is the speed of travel in miles per hour; W is the effective width of the machine in feet; L is the length of the field in rods; N is the time required for turns at the end of the field expressed in fractions of a minute; and A is an overall service and rest allowance expressed as a decimal. For steady work the value of A will usually be between 0.20 and 0.35. Where short rush jobs are to be done the value of A may be less than 0.20. Where additional time is required for mixing materials or preparing seed, A may be as high as 1.00 or even greater.

For any particular time the most convenient method for estimating A is to ask the farmer how many minutes out of each hour of the day are needed to oil, grease, and adjust machinery and to allow for rest and relaxation of the operator. If the farmer estimates that 10 minutes out of each hour would be required, then the 10 divided by the remaining 50 minutes of an hour would give 0.20 as the value of A . If the farmer estimates that 15 minutes would be required, then the 15 divided by the remaining 45 minutes of an hour would give 0.33 as the value of A .

In order to save time in calculation, use table 1 in the appendix to find the value of the first term of the equation for a representative selection of speeds and widths. Likewise table 2

in the appendix will give the decimal equivalent of $\frac{16 SN}{3 L}$ for the second term of the equation where N is $\frac{1}{2}$ minute.

Where conditions on a given farm are uniform the reader should study pages 16 to 17 in the main body of the report wherein it is shown that from a calculation for one width of machine the comparative time can be calculated for this given set of conditions for any width of machine.

To illustrate the use of the equation and tables 1 and 2, assume that a 6-foot machine is used at a speed of 3 miles per

hour in a field 80 rods long. Assume that the time required for turns is $\frac{1}{2}$ minute and that A is estimated as 0.25. Table 1 shows for a width of 6 feet and a speed of 3 miles, 0.46 hour, which is the value for the first term of the equation. Table 2 shows 0.10 as the value for turns of $\frac{1}{2}$ minute each in fields 80 rods long with a speed of 3 miles, making the second term of the equation $1 + 0.10$ or 1.10. Since A is 0.25, the third term would be 1.25. The equation now reads

$$T = (.46) (1.10) (1.25)$$

which gives 0.6325 or, to the nearest two decimals, 0.63 hour as the time required for this operation under the assumed conditions.

A New Technique of Field Crop Labor Analysis^{1, 2}

By RAYMOND T. BURDICK
Chief, Economics and Sociology Section,
Colorado Agricultural Experiment Station

Part I.—INTRODUCTION

This study is the development of a technique for analyzing field crop labor in order to recognize and measure the more common factors which affect the hours per operation per acre. With this technique, the influence of each variable can be analyzed separately. Proposed changes in cultural practice can be studied in relation to past methods of production to discover the effect upon total labor requirements per acre. By the use of customary cost valuations these variations in labor requirements can be expressed in monetary values, thus permitting a direct comparison of the effects of various crop practices upon income, other things remaining constant.

Then substitutions of production methods can be made until the optimum is found under the given conditions for the production of a given crop. After this point is reached, crops can be substituted in the rotation to study the effects upon net returns for the farm as a whole.

REASONS FOR THE SHIFT IN EMPHASIS

The original proposal assumed that this sequence in analysis could be derived from historical data. It was soon discovered that what was needed was a method for diagnosing specific cases and for helping individual farmers to make decisions looking to the future.

The primary reason for this shift from analysis of historical crop data to a more theoretical general purpose analysis arises from the fact that historical data caused one to look backward in all matters of analysis, while the actual conditions under which

¹ Based upon analysis of data secured from Farm Business Analysis Studies as affected by World War II and data secured from the Effects of Recent Changes Upon the Economic Relationship Between Colorado Ranch and Range Properties as well as from analysis of data secured from earlier projects.

² A dissertation submitted to the faculty of the Department of Economics, University of Chicago, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, December 1946, modified for publication.

crops are produced are changing, requiring a constant looking ahead and forecasting of the effects of proposed changes, especially if the results of the study are to be of continuing value in a changing world. The time required to secure field data, analyze them, and put them in useful condition meant that a new practice was being tried by the time one had knowledge from the analysis of the old. "What will it cost?" is the question, not "What did it cost?"

Operating a farm constantly necessitates making decisions. These decisions will be made by farmers either acting upon their own knowledge and initiative or in response to suggestions from others. Every change in the conditions under which farming is done results in the need for a decision by each individual farmer as to how he will modify his operations in response to these new conditions. In the past, workers in agricultural experiment stations, when called upon to give advice to farmers as to the desirability of a specific change, have typically depended upon historical data of past experience for their conclusions. This situation in effect meant that new methods had to be tried before any evidence could be secured as a guide in analysis of the probable effects upon labor requirements or upon cost. To aid in determining the wisdom of a proposed change in the organization or layout, a farmer used as a guide a farm with similar conditions, the performance of which was known from past records; or he made a decision largely upon intuition and guess. As will be developed in subsequent sections of this study, the need was for some tool of analysis which would reduce the margin of error in estimating in advance what might be expected from a proposed change insofar as it affected labor requirements and costs.

SOURCE OF ORIGINAL DATA

The historical data for this study were secured by means of a detailed cost route, which may be defined as a method of securing closely supervised farm records where one man visits approximately 20 farms from 2 to 4 times per month. On these trips he secures labor, crop history, livestock feeding, inventory and financial data in as much detail as possible within the limits of available methods of measurement and the willingness of farmers to supply continuous data. The study was made in the Fort Collins-Eaton-Greeley area in northern Colorado, beginning in 1922 and continuing through 1933. Since 1933 financial data and production records have been secured each year in this area but labor studies were omitted after 1933, except for occasional spot analysis of some new method.

DATA AVAILABLE FOR ANALYSIS

Financial data for the farms included in the original research project are available from 1922 to date. Actual prices received for farm sales were reported, with minor exceptions, in relation to unit weights. So far as possible this same detail was secured for farm purchases. Depreciation, which in the long run is equivalent to a cash expense, was calculated at first on the basis of farm experience as to anticipated life expectancy of machinery and buildings. As farmers and research workers became increasingly familiar with the depreciation rates allowed by the Federal Government in income tax reports, there was a strong tendency toward the use of these Federal rates without critical challenge.

Quantity data during the years 1922 to 1933, inclusive, were secured for hours of work by men and horses and equipment; for pounds of feed consumed by livestock; for quantities of materials used in crop production, and for measured areas of crops and crop yields.

The hours of labor by specific operations was the most difficult quantity measurement. The difficulty was of two sorts. First, the problem of securing continuous alert recording by the individual farmer of the time spent by men and power on the different operations resulted in data that were less reliable than desired. There was a constant tendency to lump items or to report one operation and perform several. The second difficulty arose from the physical conditions. During the years studied the rainfall showed wide variations. The farms studied had sandy soils and heavy phase silt-loam soils and nearly every phase in between. Some of the fields were low and poorly drained, with an excess of alkali; some fields were high knolls above the irrigation ditches. Some fields were of an even slope so that irrigation was largely a mechanical operation, while other fields were rolling so that the irrigator must be ever on guard to direct the water to all parts of the field. Some fields had straight sides; others had crooked, winding boundaries because of irrigation ditches or other physical features. Some of the farms had good management as demonstrated by excellent physical condition and fields comparatively free from weeds, while other fields were weedy or in poor physical condition. Some farms were under irrigation ditches with water rights that permitted the application of water whenever the farmer desired, while others had very uncertain water rights. Some years there was a serious shortage of irrigation water which, together with drouth, made crop yields highly variable. Some of the farmers had modern new equip-

ment, while others had old, badly worn or inefficient equipment. There were many makes and widths of machinery. Some farmers had young, heavy draft horses; some had older, slower, and less efficient horse power. Some men had old-style tractors, while others purchased general-purpose tractors as soon as they came on the market. Yet to one driving along the highway the farms gave every indication of being representative of irrigated farms in the community. Whether they were better or worse than the average farm is beside the point for purposes of this inquiry, since cause and effect relationships and the effects of variations in factors are the problems under review. Such analysis can be as true on good farms as on average farms.

Need for analysis of the prevailing system of farming.—

The fact is that farmers everywhere find themselves living in a world of change. This valley is no exception. When the writer began to study irrigated agriculture in this valley in 1922 it was assumed that 3 years' analysis of the details of farm operation and management would furnish all the material needed to answer any farm management question about the valley. Actually, at the end of 3 years the data merely set the stage for the study of an almost endless combination of variable conditions found during those 3 years. The Colorado Agricultural Experiment Station decided to continue the study.

In addition to this purely individual farm phase of analysis the added years of accumulated data brought increasing evidence of broader problems reaching beyond the confines of individual farms and touching on national and international relationships.

These dynamic conditions were a continuous challenge to the farm management worker. The old methods of attack were slow, costly, and inadequate to the task facing students of agriculture. Some of the basic premises of farm management as reviewed in the following pages will serve to stress this fact. The variables enumerated on pages 10 and 11 show the need for a great volume of statistics to cover the main variables and combinations of variables. A brief survey of the existing data indicated their inadequacy as a source of answers to the major problems. The writer found increasing need for a tool of analysis which would serve as a means for estimating what would be the effects of a proposed change in operating methods or in crops grown before such a change had actually been made.

THE THEORY OF FARM MANAGEMENT

This study tends to emphasize the theoretical aspects of farm management. The theory of farm management in general

is the theory of the firm, namely, the theory of individual decisions by owner operators. The word "theory" refers to what should happen under the assumed conditions in the absence of unexpected obstacles.

The present study is an attempt to clear up some uncertainties found in the problem of analysis of field crop labor requirements and the limitations in their use in applying the economic principles of marginal analysis to management decisions. The equations and analyses in this report are designed for use by the individual regardless of his relationship to average conditions. The central theme of this report is the quest for theoretical means to strengthen the attack on the problems of the individual farmer.

The theory of the firm is the key to progress for the individual farmer. How to cut down the errors of estimate is the kind of help needed by the forward-looking farmer. Averages mean that some farmers did better and some did worse. Why did some of them do better? The averages do not show this. What can one expect from a given set of conditions? The averages seldom include all the conditions nor allow for possible variations in them. The individual needs this kind of information. Starting with a going concern the farmer needs to know how to estimate the results of changes in the organization and operation of this specific farm. Averages are better than nothing, but best of all is some clue to what will take place on this specific farm. The problem was to find some method for analyzing farm operations before they were performed in place of waiting until the work was done and securing a record of actual hours. At first endless calculations of many possible combinations of field conditions were tried, as enumerated on pages 10 and 11. Then a search was made for a mathematical statement or an equation or formula which would serve as a general statement to replace the tables of calculations.

Part II.—METHODS OF ANALYZING FIELD CROP LABOR SPECIFIC FIELD OPERATIONS

A study was made of the factors which modify the hours of work per acre. These have been summarized on pages 10 and 11. It was apparent that the number of factors whose influence was of sufficient importance to warrant further analysis was too great to be explained by the existing data. Not enough records were available to be able to say that the variations in averages were in all cases significant from a statistical point of view, nor

could the averages be kept up to date with new developments in technology. With these limitations in mind other ways were sought to arrive at some measure of the influence of variations in farm practice upon labor requirements in crop production. This trail proved fruitful. It suggested a different method of attack upon the problem.

A PROPOSED METHOD FOR ANALYZING FIELD CROP LABOR

To secure results in which a farmer could have confidence for application to his conditions, a method was devised to test by mathematical calculation the factors which were judged to be significant.

Careful study of the 1922 to 1933 data, and review of crop cost studies and of other references which appear in the following pages, seemed to indicate that the following factors should receive more analysis to find their effects upon the number of hours per acre required for various operations.

1. Length of field.
2. Width of machine.
3. Speed of travel.
 - (a) Changes in speed due to slope of land or soil conditions.
4. Time required for turns.
5. Soil and weather conditions.
 - (a) Making extra operations necessary.
 - (b) Affecting crop yield.
 - (c) Slowing up speed of travel.
6. Possibility of combining operations or of overlapping.
7. Service time required for necessary servicing of machinery, for rest and unknowns.
8. Distance from farmstead to fields.
9. Uncertainties, such as
 - (a) Shape of field.
 - (b) Effect of sustained long hours upon efficiency of horses or men.
 - (c) Slippage of tractor wheels.
10. Unexpected breakage and delays.

A review of these factors will suggest that the effect of several of them can be measured. Other things being equal, a 10-foot machine should require one half the number of hours per acre necessary with a 5-foot machine. A 3-mile speed should require one half the time necessary with a speed of 1.5 miles per hour.

Previous work on similar methods.—Other workers have made careful studies of some of these factors. "One of the reasons for the saving of labor with large fields is the time lost in turning in small fields."¹ "There is a tendency to rest more often when turns are frequent."² "The plowman wishes to reduce to a minimum the time spent in turning and in running with plows out of the ground."³ "It seemed to me that (F. W.) Taylor's theories and those of his followers could be applied to advantage in devising ways and means for increasing the efficiency of farm labor."⁴

McKibben made an attempt to express some of these factors in an equation. He says:

While it is obvious that the effective capacity of a field machine is some function of (1) width, (2) operating speed, and (3) interruptions, the relationships between these factors under varied field conditions are not always so evident. For example, it has been the common experience of the operators that the effective capacity of a field machine is frequently not increased in proportion to increases in either its width or its operating speed The effect of interruptions . . . upon the capacity of wider machines and higher speed machines is one of the most important and least understood of the reasons for the disappointing results often experienced in using such machines under adverse conditions . . . for example, interruptions caused by stones, stumps, weeds, trash, filling seed or fertilizer boxes, inferior constructions, inefficient operation, careless maintenance, etc., . . . often tend to be in proportion to area.⁵

The conflicting influences of some of these factors is indicated by reference to other studies. "Theoretically 40-inch would require 5 percent more time than 42-inch corn rows. Averages show practically no difference."⁶ "No significant relation is shown between size of field and hours per acre for plowing, or work on

¹ MYERS, W. I.: *An Economic Study of Farm Layout*, Cornell Experiment Station, Memoir 34 (June, 1920), p. 411.

² *Ibid.*, p. 412.

³ TOLLEY, H. R.: *Laying Out Fields for Tractor Plowing*, U.S.D.A., Farmers' Bulletin 1045 (May, 1919), p. 3.

⁴ SEEDORF, J. J. W.: "Methods and Results of Research Work on the Efficiency of Human Labor on German Farms," Proceedings of the Second International Conference of Agricultural Economists, (Ithaca, New York, 1930), p. 952.

⁵ MCKIBBEN, E. G.: "Factors Determining the Capacity of Field Machines," *Agricultural Engineering*, II (February, 1930), p. 55.

⁶ TOLLEY, H. R., and CHURCH, L. M.: *The Standard Day's Work in Central Illinois*, United States Department of Agriculture, Bulletin 814 (April, 1920), p. 11.

corn. Other factors were more important than size of field in explaining variations in cost."⁷

While these comments indicate the need for critical analysis, there apparently are no published studies which follow up these leads. Many workers have tried to smooth out such variables by including a large number of records as the basis for average results.

But the rapid growth of technological progress in agriculture following the introduction of the general purpose tractor, has served to emphasize the inadequate nature of historical averages.

It is apparent that a combination of the failure to get down to the fundamental factors in the situation together with the lack of a usable method of attack has prevented either the engineer or the economist from making the necessary calculations to keep up with inventions and show their effects upon costs.

RELATED STUDIES IN INDUSTRY

Students of scientific management in industry have a more complete analysis of this problem. While the conclusions which they have reached under factory production cannot be transferred without change and applied under field-crop conditions, the methods which they have developed are significant as offering a clue to the method for analyzing field crop labor requirements. In industry attention has been given to the time necessary for (a) unavoidable delays, (b) allowance for the necessities of life, (c) allowance for fatigue, and (d) handling time, i. e., preparing materials before machine work begins.

Merrick and Barth have concluded after much analysis that a minimum of 20 percent should be added to "cycle time," i. e., the straight time with no delays for fatigue and other allowances.⁸

Significantly, in these industrial studies, cycle time is given, and the emphasis is placed upon a reasonable percentage allowance. In the case of field-crop studies, neither cycle time nor information as to an allowance percentage is available. Accordingly, with the present state of knowledge, a workable equation must be constructed in such a manner that it will include both these unknowns. As will be seen from equation (1) for field crop labor, both cycle time and a service allowance are included. But cycle time in agriculture differs from the cycle time in industry by reason of the difference in the basic factors. For example,

⁷ YOUNG, E. C., and SMITH, F. V.: *A Study of Farm Layout in Indiana*, Indiana Experiment Station, Bulletin 423 (1937), p. 14.

⁸ ALFORD, L. P.: *Management's Handbook*. (New York: The Ronald Press Co., 1924), p. 824.

the cycle time for a specific factory machine can be read from a chart of machine speeds and depth of cut, if metal work is involved. No such rigid relationships exist in agriculture. The approximate speed, approximate width of cut, approximate time for turns, etc., are the materials for crop field analysis with which the engineer or economist must work.

THE EQUATION FOR ESTIMATING FIELD CROP LABOR

The factors listed on page 10 include some which can be given definite values and others which are subject to no specific estimate. The writer has identified five factors which affect (T) the total hours per acre required for a specific farm operation: (1) W or effective width of the machine in feet, (2) S the actual speed of travel in miles per hour, (3) L the length of the field in rods, (4) N the time required for turns at each end of the field expressed in fractions of a minute, and (5) A the service and rest allowance expressed as a decimal fraction. With these factors

$$T = \frac{8.25}{S W} \left(1 + \frac{16 S N}{3 L} \right) (1 + A). \quad (1)$$

In equation (1) the first term, i. e., $\frac{8.25}{S W}$, gives the hours

required to cover 1 acre when no allowance is made for turns or any delay. The process for development of this term was as follows: An acre of ground covers 43,560 square feet. A machine 1 foot wide would go 8.25 miles to cover 1 acre. With a speed of 1 mile per hour it would also take 8.25 hours to cover the acre. This may be considered as the base or starting point. It is apparent that a machine 2 feet wide, other things being equal, would cover the acre in half the time or 4.125 hours. It is also apparent that a speed of 2 miles per hour would also cut the time in half. The hours for 1-foot machines at 1 mile per hour, if divided by the product of speed and width, will give the hours for any combination of speed and width. Hence the first term of the equation gives the straight time to which must be added the necessary time for turns and all other items which delay the work.

The second term, i. e., $\frac{16 S N}{3 L}$, gives the added time involved

in turning around at the end of the field. This was secured as follows: A field 80 rods long was used as a base for this calculation. The 1-foot machine in going 8.25 miles in an 80-rod field will turn 33 times in covering an acre, which will require 33

minutes or 0.55 hour when turns require 1 minute each. This is 6 and 2/3 percent of the 8.25 hours required for straight work at a 1-mile speed. But 6 and 2/3 percent is the same as 1/15. It is apparent that a field 40 rods long would require twice the time for turns, compared to the 80-rod field. Hence 80 divided by length of field would give the ratio of the time for turns for any other length of field compared to the base time for an 80-rod field. If a turn is made in 1/2 minute, this would be one half the time for 1-minute turns. Speed works in an opposite manner. With a 2-mile speed and no change in the time per turn, the time per acre for turns will be twice as large a percentage of straight time in contrast to the percentage with the 1-mile speed. Bringing all these items together this term of the equation reads

$$\frac{80 S N}{15 L}, \text{ which reduces to } \frac{16 S N}{3 L}.$$

It is necessary to add the whole number 1 in the parenthesis so that the straight time can be multiplied by a rate which will include itself plus the added time for turns.

The third term in the equation merely introduces the service allowance which is an overall factor of safety added to the combined time for straight work plus the time for turns. A covers all other items not otherwise identified. Again the whole number is added to permit direct multiplication in the equation. W, S and L are factors which can be measured for any specific farm condition. N is more indefinite since, in fact, it may differ for each turn during a specific field operation. S can be taken directly from factory specifications for tractors, or from the speedometer in the case of trucks. But with animal power S becomes uncertain. The individual farmer can estimate his horses' speed of travel quite closely under specific conditions. The "average" speed of horse travel should be considered as a central tendency and not a definite datum.

Others have reported on the possible speed for work horses.

Work horses should not be hurried, they are more efficient when working at a given horse power when pulling a heavy load at a slow speed than a light load at high speed . . . a safe tentative recommendation . . . is a tractive draft equal to 10 percent of body weight pulled at about 2 and 1/2 miles per hour.⁹

Teams ordinarily walk a little less than 2 miles per hour with heavy implements, like plows and disks, and about 2 miles an hour or a little more with lighter implements. If the rows are so long that these rest periods require stops before a row is finished, the advantage of long rows disappears . . . It is sufficient if the rows are 1/4 or 1/2 mile in length, . . . If the rows are very long there

⁹ BRODY, S., and TROWBRIDGE, H. A.: *Efficiency of Horses, Men and Motors*, Missouri Experiment Station Bulletin 383 (1937), p. 10.

is liable to be waste of time from men quitting earlier than the regular time, for the reason that to go another round would keep them beyond the regular quitting time.¹⁰

"Horses working alone travelled at the rate of 1.615 miles per hour (plowing)"¹¹

With these three studies as a basis, it seems that 2.5 miles per hour can be taken as about top speed for best utilization of horse power, while speeds of 1.5 to 2 miles per hour may be common. Illustrations of the effect of S upon T will be shown later.

For some field operations N approaches zero since there is no time needed to place equipment in a specific position for a return trip. Representative of this condition are most operations in seedbed preparation and some harvesting operations, such as for grain and hay.

For other operations equipment should be exactly placed before a return trip is started. Typical of this condition are planting, cultivating and harvesting of row crops. For these operations the writer has made studies which indicate a tendency for N to approximate 1/2 minute.

The safety factor of A never can be a fixed value. It will vary from day to day, from operator to operator, and in relation to the duration of the operation. For short periods of time A may be zero. Industrial workers have found that at least 20 percent should be added to all other time to insure safe operation. This should be accepted as a minimum value of A for farm operations unless specific evidence justifies a different value. This means 10 minutes out of each hour for rest. When servicing equipment is included in A 20 percent is not large enough. A value of at least 0.35 for A is recommended for tractors to make allowance for the slippage of wheels.

In certain field operations which involve much handling of material, such as spraying, A may exceed 1.00. Part III contains some analysis of published studies which indicate possible values of A. The problems related to a selection of a value for A are discussed in parts IV and V. A should be considered as the factor which absorbs errors in the measurement of all the other factors. Since there is no one fixed value for A the writer uses in any specific instance the farmer's estimate with 0.20 as a minimum.

For those who seek representative values for the factors in equation (1), N and A will be the most difficult to evaluate. N may be determined by the use of a stop watch.

¹⁰ SPILLMAN, W. J.: *Farm Management*, (New York: Orange Judd Publishing Co., 1923), p. 289.

¹¹ SEEDORF, J. J. W.: "Methods and Results of Research Work on the Efficiency of Human Labor on German Farms," Proceedings of the Second International Conference of Agricultural Economists (Ithaca, New York, 1930), p. 957.

Where T is available and all other factors are known, the value for A may be found by the following equation,

$$1 + A = \frac{3 T S W L}{8 \frac{1}{4} (1 + 16 S N)} \quad (1a)$$

A preliminary test of the relationship between width of machine and hours under any given set of conditions shows that this relationship can be expressed graphically in terms of a rectangular hyperbola. Assuming this to be the case, it may be convenient at times to have an equation to aid in developing the equation of the rectangular hyperbola.

The question may be asked, "How can one be sure the time per acre required for any given set of conditions will vary with the width of machine used in a manner that represents the rectangular hyperbola?"—a rectangular hyperbola being a curve which can be defined as the locus of a point the product of whose distance from two fixed perpendicular lines is a positive constant, i. e., $xy = c$.

By reference to equation (1) it will be seen that $\frac{8.25}{S W}$ is the straight time per acre with no extra time for turns or service. It is apparent that by holding S at any fixed value the time per acre will vary inversely as the values of W are increased, i. e., Ts,

straight time, equals $\frac{8.25}{S W}$, or, multiplying both sides of the

equation by W, Ts W equals $\frac{8.25}{S}$. Since S is one of the variables

held constant in any given set of conditions, it is apparent that any change in the value of W in this given set of conditions will not change the value of S, hence an increase in the value of W will be reflected in a proportional change in the opposite direction for the value calculated for Ts. If one uses the original equation (1) for the given set of conditions, it is apparent that specific values will be assigned to all the variables, and the equation

Ts W = $\frac{8.25}{S}$ can be rewritten:

$$T W = \frac{8.25}{S} \left(1 + \frac{16 S N}{3 L} \right) (1 + A) \quad (\text{modified equation (1)})$$

It is apparent that the only effect of this is to produce for the right side of this modified equation a value which represents the product T W. And the product will be a constant for any given set of conditions.

The only variables which must be removed from modified equation (1) in order to have an equation which will solve this "constant" will be T and W. By substituting C for T W, one then has

$$C = \frac{8.25}{S} \left(1 + \frac{16 S N}{3 L} \right) (1 + A) \quad (2)$$

With this definition of C a new equation can be made

$$T W = C \quad (3)$$

This is the equation of the rectangular hyperbola rewritten with the materials of equations (1) and (2).

A few illustrations will serve to demonstrate the possible variations in C. Assume a speed of 2.5 miles per hour in a field 80 rods long with turns of 1/2 minute and A at 0.20. Under these conditions C becomes 4.29. If, with these conditions, S is reduced to 2 miles per hour, C becomes 5.27. But with a speed of 1.5 miles per hour in fields 10 rods long with turns of 1 minute and A at 0.30, C becomes 12.87.

Equation (3) has a practical use for rapid comparisons. Assume that one has need for data on the time required for each operation on a specific farm. If he will take the time in hours per acre for one operation with a machine of a specific width in feet and substitute these values of T and W in equation (3) he can calculate a value for C which will be true under the conditions existing on this field for any other width of machine. From this value of C, by dividing by the width of any other machine to be used under these same conditions, he can find the corresponding value of T. Thus by one actual observation under the conditions on this field one has sufficient data to calculate the approximate time per acre needed for each operation under these same conditions. Or again, assume that the conditions to be studied are representative of a group of farms. Here one can use the values for these assumed conditions in equation (2) to secure the value of C for equation (3). From this, one can calculate the hours per acre for all operations for this group of farms.

In all cases it should be remembered that the hours found by equations (1), (2) and (3) will be "crew hours." Where one man handles horses or tractor this will also be the man hours per acre for the given conditions. To find horse hours it will be necessary to multiply, for each operation, the crew hours by the number of horses in the team.

Since yield influences actual hours for harvest and itself is influenced to an unknown extent by seedbed preparation, yield

cannot be accurately incorporated into equation (1) hence it was omitted from the analysis.

Part III.—ANALYZING FIELD CROP LABOR BY MEANS OF THE EQUATIONS

Stated in terms of equations (1) and (2), the question arises, "What is their influence or reliability in contrast with other methods of labor analysis?" Two lines of approach should prove helpful in answering this question: The first, to analyze published data, and the second, to calculate probable field labor requirements and compare the results with actual records.

Since A is the variable which has received the least attention in the past, a few reports will be analyzed to determine if a valuation of A can be found for the reported conditions.

TESTING THE VALUATION OF "A" BY ANALYSIS OF FIELD LABOR STUDIES

One of the most carefully reported studies of the labor hours used in crop production will be used first.

Time clocks on tractors at the experiment farm show a variation of 15 per cent in running time between different operators with the same kind of equipment, doing the same kind of work . . . Servicing includes greasing, oiling tightening bolts, adjusting implements, replacing worn parts. . . the percentage of the field operator's time required for servicing varies from 6 per cent to 40 per cent, or out of every 5 hours he works, 1 hour for servicing.¹²

Stated in terms of equation (1a) this would give A a value of 0.25 with a range of value from 0.064 to 0.667. Some of Starch's data will help to illustrate the point. He shows that a 56-inch plow operates at a speed of 2.29 miles per hour on stubble ground, with 1.03 hours total time per acre, of which 0.77 is running time.¹³ The difference, or 0.26 hour, is the service allowance or 0.333 for this illustration. The length of field or time for

turns is not stated. However, from $\frac{8.25}{S W}$ one can derive the straight time for plowing or 0.758 hour, leaving 0.012 for turns or 1.56 percent. Since length of field is not stated, one can assume 160 rods (page 11 and following pages indicate an 800-acre farm with fields 160 rods long).¹⁴ Then, by substituting these values

in the equation $\frac{16 S N}{3 L} = 0.0156$, $N = 0.204$ minute. This seems to be a reasonable interpretation. The situation can be restated

¹² STARCH, E. A.: *Farm Organization as Affected by Mechanization*, Montana Experiment Station Bulletin 278 (1933), p. 48.

¹³ Ibid., p. 51.

¹⁴ Ibid., p. 18.

as follows: With a 2.29-mile speed and a 4.67-foot machine in fields 160 rods long with 0.204 minute required for turns, the service allowance is 0.333.

Again Starch shows the time for cultivating corn with 4-row equipment to be 0.21 hour running time and 0.28 hour total or 0.07 hour service allowance.¹⁵ This gives 0.333 as the value of A. The width between rows is not stated, but it would be at least 44 inches since more time than that stated would be required with 42-inch or narrower rows and a 2.77-mile speed. The speed of 2.77 miles per hour as shown would require 0.203 hour per acre for straight work, leaving 0.007 for turns. Using equation

$$\frac{16 \text{ S N}}{3 \text{ L}} = \frac{0.007}{0.203} \text{ with a 160-rod field, N} = 0.095 \text{ minute which}$$

indicates a very small margin per turn. Certain errors appear in the data.¹⁶ A 20-foot spike harrow is shown as requiring 0.11 hour running time with a 3.62-mile speed. If no time is allowed

for turns this 0.11 would be 0.114 by the equation $\frac{8.25}{\text{S W}}$, leaving a

minus value for turns, while on the same page a 20-foot spike harrow at 3.3 miles per hour used 0.16 running time, yet this speed requires 0.125 hour of straight time, leaving 0.035 for turns. The only explanation would be in the failure to record the actual effective width in each case, if one may assume that all other data are exact.

This report was for tractor operation. Since speed was reported it was possible to calculate the service allowance with reasonably satisfactory results. It was approximately 0.33 for the two cases calculated.

Claud K. Shedd and Edgar V. Collins show that a 2-row corn picker at a 3-mile speed in a 40-rod field required 0.55 hour per acre crew time, "not including the time for servicing the equipment." The width of row or time for turns was not reported, but the authors state, "a 2-row machine would harvest 2 and 1/2 acres per hour (if operation were continuous at the 3-mile speed)."¹⁷ The 2 1/2 acres per hour are equivalent to 0.40 hour per acre, which is practically the time for a 7-foot width machine (0.393) under the stated conditions, so presumably 42-inch rows are meant.

¹⁵ Ibid., p. 83.

¹⁶ Ibid., p. 69.

¹⁷ SHEDD, C. K., and COLLINS, E. V.: *Mechanizing the Corn Harvest*, U.S.D.A., Farmers' Bulletin 816 (1938), pp. 3-4.

Using equation (1a) and assuming $1/2$ as the value of N, A has a value of 0.167. If their servicing of machine is added, some of which undoubtedly belongs in A, there would be from "1 to $1\frac{1}{2}$ hours a day"¹⁸ of service time. Using their low estimate of 1 hour together with the calculation of 0.167, one secures a total value for A of 0.333, i. e., with 0.167, for service 0.833 remains for work. With a 10-hour day, and their 1 hour for service, the 0.833 times the remaining 9 hours gives 7.5 hours field work, or 2.5 hours for all kinds of service allowance. The 2.5 is $33\frac{1}{3}$ percent of 7.5 hours; therefore, when using their 1 hour for service A has a value of 0.333.

Another case from this same study shows 0.83 crew hour per acre when 1 man operates the entire outfit.¹⁹ The value of A here is 0.81, assuming all other conditions as constant, which is contrary to the fact because all the hauling to the elevator now appears against the crew operating time, while in the first case 1 man spent practically full time hauling while the other man operated the corn picker. Even this comparison is not exact, since the 2-man crew worked in a 40-rod field yielding 79.3 bushels per acre, while the 1-man crew worked in an 80-rod field where corn yielded only 59.8 bushels per acre; i. e., the 1 man had to travel 32.5 percent farther along the corn rows to pick the same number of bushels. Actually he also used 40.3-bushel loads compared to 34.9-bushel loads for the 2-man crew.

This case illustrates the possible error arising from changing more than one variable at a time in attempting to study the effect of one variable, in this case the size of crew. Use of equation (1) would have permitted correction of the data in this study so that a comparison for the single variable could have been made.

In 1940 the writer secured a report on corn cultivation on a large field in eastern Colorado where a track-laying tractor drew a 6-row cultivator. When all the other variables in the operation were accounted for, calculation placed a valuation of 0.06 for A. The farmer who operated the tractor indicated that he believed he had done "more than a normal day's work." This calculation as to the value of A verified his statement.

GENERAL ANALYSIS OF CROP LABOR STUDIES

A review of farm management literature suggests that in many cases the authors were not aware of the variables involved and the effect of these variables upon their results. The equa-

¹⁸ Ibid., p. 5.

¹⁹ Ibid., p. 4.

tions developed in part II can be used to show the theoretical hours per acre which might be expected from a specific study and to point out peculiarities in the reported data which are not explained by the author. A few cases will serve to demonstrate the possibilities.

ANALYSIS OF NORTHERN COLORADO LABOR DATA

During the years 1922 to 1933 detailed records of labor use were secured. Unfortunately no attention was given to the details of S, W, N, L, or A. Great difficulty was experienced in keeping the farmers' reports from containing statements for combined operations. Only in a few instances was it possible to secure labor reports separately for individual fields. From these special cases the writer selected 28 records of plowing where the length of the field was definitely recorded. Horse power was used in each case. The length of field varied from 25 to 158 rods. The total man hours per acre varied from 2.32 to 6.84. Multiplying the values of L and T for each case to secure a product TL resulted in values for TL from 135 to 711 for plowing. A similar calculation for various planting operations on 36 fields included extremes of 0.56 to 4.49 hours per acre on fields 25 to 158 rods in length with the product TL varying from 73 to 346. These extreme variations in T and TL merely reflect the effects of variations in S, W, N, and A, none of which were recorded.

In 1934 when the detailed labor records were not available, the writer interviewed the farmers who had formerly supplied daily labor reports. They were asked to estimate the acres of work which could be done in a 10-hour day with different machines, using horses or tractors. The width of machine was secured, but no questions were asked concerning the other variables that are used in equation (1). Their significance was not apparent until later. After analysis of other data and special observations had been made by the writer, he turned to these 1934 estimates to discover how they compared with calculated data under assumed conditions.

In order to have a basis of comparison, calculations were made using equation (1) with a 2-mile speed, turns of 1/2 minute in an 80-rod field, and an 0.20 value for A. In the following table the man hours per acre based upon the farmers' estimates for horse power are compared with these calculations.

TABLE 1.—COMPARISON BETWEEN FARMERS' ESTIMATES AND EQUATION

Operation	Width of machine	Hours per acre	
		Farmers' estimates	Calculation by equation (1)
Plowing.....	14 inches	4 to 6.67	4.53
	16 inches	4 to 5	3.96
Spike harrow.....	10 feet	0.5	0.52
	12 feet	0.5	0.44
	15 feet	0.5	0.36
Spring-tooth harrow.....	4 feet	1.25 to 1.67	1.32
	6 feet	1.00 to 1.25	0.88
	7 feet	0.83 to 1.25	0.76
Leveler.....	12 feet	0.4 to 0.67	0.44
Roller.....	10 feet	0.4 to 0.55	0.55
Grain drill.....	78 inches	0.67	0.82
	84 inches	0.83 to 1.00	0.76
	96 inches	0.67 to 1.00	0.67

Since the farmers were asked for acres per day there was an evident tendency for their answers to show "rounded" data. For example, with spike harrows the farmers gave 20 acres per day as their estimate regardless of width varying from 10 to 15 feet. Similarly 2 or 2.5 acres were considered to be a day's work in plowing whether a 14-inch or a 16-inch plow was used.

TESTING EQUATION (1) AGAINST ACTUAL RECORDS

In the fall of 1942 Farmer No. 28, who was in the original group studies in 1922 to 1933, decided to shift from horse power to tractor power for pulling sugar beets. In discussing the matter he estimated that a 2-mile tractor speed could be used on the puller and for clearing the space for piling beets. This, under his field conditions,²⁰ would result in 3.56 hours per acre. Actual labor records kept by Farmer 28 for the 1942 crop gave the time required for beet pulling as 3.75 hours per acre. After this experience with tractor power Farmer 28 decided to try a 3-mile speed in 1943. Under his conditions a 3-mile speed would result in 2.52 hours per acre. The actual time reported by the farmer was 2.38 hours per acre.

During the 6 years 1937 to 1941, this farmer had used 2 horses for beet pulling. When asked at what average speed he

²⁰ This work was done in a 40-rod field at a 2-mile speed. The farmer estimated that N would be 1/2 and that A would be 0.20. With these estimates 1/6 of the calculated time was added to allow for clearing the space where beets were piled.

believed his horses walked he replied that they walked very slowly, probably at a speed of not over 1 1/2 miles per hour. Using 1 1/2 miles as a basis, with all other conditions as stated, the hours required for beet pulling would be 4.62. The 6-year record as kept by this farmer for the years 1937 to 1941 averaged 4.78 hours per acre for beet pulling.

In the fall of 1945 an agricultural engineer made a time study of the hours per acre required to pull sugar beets with horse power. Prior to the field trial the engineer estimated that the horses would travel at an approximate speed of 1 1/2 miles per hour. Equation (1) for this speed, N of 1/2 and A of 0.20 showed 4.62 hours per acre for pulling sugar beets. The engineer's records showed 4.45 hours per acre.

A machinery manufacturer was trying out a new combined sugar-beet topper and loader in Colorado in the fall of 1945. He estimated that the machine could not safely go faster than 2 miles per hour. He also estimated that the machine should cover 3 acres in a day. Using the known conditions for the field (20 rods and 20-inch row) where the machine was being tried, together with N of 1/2 and A variable from 0.20 to 0.35, the writer calculated by means of equation (1) that it would take from 3.77 to 4.25 hours per acre with this machine. Since the operation was performed under experimental conditions there were very few days when the machine was run continuously. The best day's operation showed 3.75 hours per acre while the second-best day required 4.05 hours per acre, which suggests that the assumptions gave close approximations to the conditions of practical operation.

In all these tests the equation gave results which were close to the actual record.

These illustrations of the use of equations (1) to (3) indicate that previous studies can be analyzed to discover probable valuations for each factor in the equations. The equations likewise can be used to estimate the hours per acre for any assumed conditions. If assumed conditions prove to be actual conditions, the equation gives the exact answer in hours per acre. There is no margin of error in this case. If actual conditions vary from the assumed conditions, then the hours per acre will differ from the calculations.

It is important to remember that neither the average of past field data nor the estimate made by an equation, wherein the field conditions appear with specific values, can give more than an approximation of what hours per acre might be expected the

next time a farmer goes into the field. The width covered and the speed of travel in an open field are not unique values as is the case with the speed and width of cut of a machine lathe. Width covered by a machine in a field is affected by the farmer's ability to drive in a straight line. It might be compared with a machinist working with a hand file. No stroke can be exactly duplicated. No trip across a field with power and equipment will be exactly like some previous trip.

While all this is recognized, farmers must continue to make decisions. Shall they depend insofar as these decisions are based upon the time required to perform a specific operation upon a field, (a) on the average of their own past records, (b) on the average of the records on other farms, (c) on their memory, or (d) on estimates which are based on the anticipated conditions under which the work will be done? When the work is completed and a record is kept of the actual hours required, the record will not be identical with any one of the four possibilities. To which one will it be closest? It will be closest to the one which was based on conditions the nearest to those under which the farmer actually operated.

With these equations used in this report, one can estimate how many hours it should take to do a specific operation on a specific field under conditions as stated. If the farmer is an accurate judge as to his conditions, then the estimate will be close to the actual time found when the work is done. If the farmer's judgment is poor, the estimate will be far from the fact.

Part IV.—FIELD CROP LABOR AND THE MARGINAL PRODUCTIVITY THEORY

The previous parts have developed a flexible method for estimating hours for field crop operation where the operating conditions are known. What are the possibilities for the use of this tool as an aid in marginal productivity analysis of labor requirements in crop production? Some general considerations require discussion before proceeding with such an analysis.

The theory of marginal productivity analysis deals with mathematical manipulation of infinitely small increments of factor inputs and resulting outputs. To be useful to business men and to agricultural economists, marginal analysts will find it necessary to work with quantities of factors which are in terms significant for farmers. The writer has found no such analysis using specific data showing hours of man labor on crops as the variable factor. One possible reason for this situation appears

to be the form in which field crop labor requirements have been previously reported. This empirical evidence was not secured to be used in marginal analysis but rather as a means of stating conditions or establishing standards for field work.

Also labor cannot be effectively applied to land unless at the same time the labor uses the necessary power and equipment to do efficient work. In the discussion which follows labor alone will be emphasized, but in every case "labor" will mean labor plus the necessary power and equipment.

The writer has accepted the statement of H. A. Millis and R. A. Montgomery as indicating the general procedure of marginal analysis.

Marginal physical productivity means the increment of output caused by employing an additional unit of labor (as an example of an agent of production) with a fixed expenditure of the other factors, and marginal value productivity (or marginal productivity for short) means the increment of value to total output caused by employing an additional unit of labor (or capital), the value of the other factors remaining unchanged. In other words, it is marginal physical productivity multiplied by marginal revenue (the additional total revenue produced by selling an additional unit of output). It is desirable to keep in mind, also, the distinction between marginal gross productivity and marginal net productivity. The former is the increment of values caused by employing an additional labor (or capital) unit with appropriate addition to the other factors, and the latter the marginal gross productivity caused by employing an additional labor unit with appropriate addition to the other factors minus the cost of the other factors.²¹

Before equations (1), (2) and (3) can be used in marginal analysis of the labor factor it is necessary to review the conditions and assumptions involved in field crop production. In all cases the necessary power and equipment are assumed to be available and used by the workers.

First one must assume that soil and moisture and temperature conditions are adequate to produce yields in excess of existing production, and second, that the past cropping has not left harmful conditions such as insect pests, plant disease or excessive weeds or poor soil structure that would limit yields. Rather the assumption is that the previous crop had left favorable conditions for the next crop.

Third, it will be necessary to assume that there are certain minimum operations in seedbed preparation, seeding, cultivation, and harvest which must be performed in order to secure a crop, and, fourth, that there are calendar limitations as to the dates when these operations must be performed to avoid reducing crop yields.

²¹ MILLIS, H. A., and MONTGOMERY, R. A.: *Labor's Progress and Some Basic Labor Problems*. (New York: McGraw-Hill Book Co., Inc. 1938), p. 195.

Fifth, that the values to be assigned to the variables in equation (1) are those which experience has demonstrated to be optimum for the conditions which exist on the given farm, and sixth, that these values for the variables are held constant during the period of analysis of the marginal productivity of field crop labor.

Something should be said as to why these assumptions are necessary. Little need be said in regard to the first and second conditions. Obviously, it would be futile to study variations in labor input where the other conditions were hostile to crop growth.

The third assumption, dealing with minimum labor requirements, deserves more attention. Naturally the omission of an essential operation in crop production would curtail output. The amount of time required for the essential operation may be subject, however, to some degree of variation. For example, the soil must be uniform where the marginal analysis is to be made since the variations in the physical characteristics of field soils cause a variation in the necessary operations and in the time required to perform these operations in seedbed preparation or cultivation. Such variations must be held constant before it is possible to analyze labor input in relation to crop yield.

The fourth assumption deals with the external influence of season. Where experience has shown that the date of plowing has had important effects upon crop yield, it would be desirable to select the date of plowing which is associated with the best yields as the basis for marginal analysis. Having made this choice, there will be the matter of depth of plowing, which bears a definite relation to the power required for plowing, since the depth affects the amount of soil which must be lifted and turned. Here again one should agree on the desirable depth of plowing for the purposes of the study. To allow variations in depth of plowing would introduce another variable at the time when inputs of labor were being studied.

The same limitation must apply to the fifth and sixth assumptions. All machine widths, speeds, rates of turning, length of field, and service allowance must be held constant. The previous analysis has indicated the wide variation in time required per operation due to variations in the values assigned to the constants in equation (1). Obviously, such variations are not related to output in the meaning which has been assigned to marginal productivity. Neither would one have a significant analysis if he started with values for the variables which were not the optimum conditions for the specific operation.

When these assumptions have been accepted where does it leave one in analyzing labor input as affecting crop yield? Apparently the only significant variable left would be that of adding an extra operation. For example, in seedbed preparation it may be debatable whether a springtooth harrow should be used two or three times. The hours required for the third operation would be a legitimate object for marginal productivity analysis. The same could be said for the number of cultivations of row crops.

The first step in an analysis of field crop production should be to seek for the optimum at every point, both as to time of operation and as to the conditions under which the operation is to be performed. In most cases the optimum will be associated with reductions in former per acre labor requirements with no predictable effect upon crop yield. Once the optimum selection of operations, of the time of operation, and of conditions under which the work is to be performed have been agreed upon, there are few farmers who would care deliberately to make work by performing extra operations.

Hence, one might conclude that the marginal productivity analysis of field crop labor has only limited significance for farmers, once the assumptions under which the analysis should be tested are defined. The equations will, however, aid in estimating the effects from changing the amount of labor or of power as one seeks the optimum combination of other factors with the marginal factor. In this case, records of the resulting output will measure the effectiveness of such changes.

At harvest time there will be some variation in hours of labor per acre, but in this case it will appear as an effect or result of difference in yields, not as a cause. There would be, however, at harvest time a variation in hours which would result in changes in the quality of the output.

Similarly, since yield affects total man hours per acre, total hours are not an independent variable. The results from marginal analysis where total man hours per acre are the variable factor, would not be reliable. Marginal analysis of field crop labor should be done with specific operations as the variable factor.

A consideration of the necessary assumptions underlying the application of marginal productivity analysis to the use of field crop labor suggests conclusions other than those commonly regarded as typical of marginal productivity. The customary relationship assumes that each additional quantity of a resource,

such as man labor, applied to a specific productive process can be related to a corresponding change in the output. The theoretical discussion has indicated the extent to which farming practices may fall short of an optimum or ideal condition, suggesting that each essential operation in crop production must be analyzed. The adjustments required to accomplish an optimum condition for each specific operation would combine, typically, to reduce the total man hours per crop acre. Two consequences will follow: (a) Some past ineffectiveness in cropping practices will be discovered, and (b) sources of labor may be found which can be diverted to other occupations.

When testing the effectiveness of farm labor by marginal productivity analysis, probably the most significant finding is that a large amount of the present-day farm labor applied to field crops has a very low productivity when measured by possible output under optimum utilization of all farm resources. The low productivity is due to the farmer's lack of adequate methods of analysis, and to the fact that many farms are not equipped with modern machinery. Farmers must be judged on the basis of their situation, and not on the basis of some desirable or ideal condition which may be their ultimate objective.

The problem of how to apply small increments of labor to farm land is another cause of difficulty in the use of marginal analysis. Operations per acre is the most convenient device by which one can make a realistic attack on the problem. Individual operations involve comparatively large doses of combined labor and capital, not small doses of labor alone. Even this method of attack has been delayed in use by the absence of any rapid form of analysis to aid in making the comparisons. For example, the addition of an extra springtooth harrowing under the assumptions used in part V would require 0.38 hour per acre for a man with a tractor and harrow. To determine the effect of this additional time upon crop yield it would be necessary to have records from two fields with all conditions identical other than the harrowing. The comparison would need to be made for a series of years before one could say with certainty that the additional harrowing produced any additional yield.

The previous discussion suggests that one of the immediate effects from the use of the equations will be to disclose methods of reducing direct field crop labor and of increasing output with the same quantity of labor. On first thought this should lead to decreasing cost, but only on the assumption that all other necessary adjustments are made. If no advantage is taken by the farmer of the released labor, his total yearly farm expense may

differ but little. Direct labor may show a reduced cost, but overhead will show an increased cost. Hence care must be used in analyzing any given layout to see whether all resources are used at optimum rates and in optimum proportions with the other resources.

Equations (1) to (3) will clear the problem of many unknowns which have previously hampered careful analysis of the conditions. The equations also indicate many ways by which farmers may add labor costs with no chance for increasing output. Under these conditions of less than optimum use of resources, the returns will be less per unit of input than after the optimum combination has been put into effect, but this is not the effect of diminishing marginal productivity. The equations also suggest more reliable measures of a change in the input of labor, and will lead to a better understanding of the problem of diminishing returns in crop production as related to the use of labor and power.

All these comments suggest the need for better understanding of the causes for low labor productivity on farms. This analysis further suggests that one of the most fruitful methods for improving agriculture will be found in increases in the amount of power and equipment handled by an individual worker.

CHIEF SIGNIFICANCE OF ESTIMATING EQUATIONS

The equations will prove useful in speeding up the adjustment toward optimum use of labor and equipment resources on farms, and stressing the penalties in the way of excess costs which are associated with less than optimum use.

It is comparatively easy under any known conditions of farming to find agreement as to the limitations which must be placed upon the valuation of any one of the constants in equations (1) or (2). Once these valuations have been determined, the equations can be used to find the resultant crew hours. Thus the effects upon field labor requirements of any proposed change in method, or in use of power, or in crops grown can be estimated quite closely in advance. These calculations help to prevent uneconomic adjustments and to point out the most promising methods for increasing efficiency. Thus by the use of these equations, assuming no change in labor rates, it should be possible to eliminate conflicting influences and to put the data in shape to permit an analysis of diminishing returns from the use of field labor under farm conditions.

Very little is known for certain about the desirable intensity of use of labor on specific operations in crop production. The

problem is complicated by virtue of the fact that the use of labor must follow a certain pattern of necessity as to time and season. At what point along the seasonal scale will these added units of labor be applied? Timeliness may be more significant than quantities of labor in effect upon output. Hence one must know what is held constant before he can judge as to the results of added increments of field labor in crop production.

SOME QUALIFICATIONS IN THE USE OF THE EQUATIONS

While optimum continuous employment may be taken as the goal for use of labor for specific operations on crops, it is less certain that it can be the goal for the crop as a whole, and it is definitely not the possibility for the farm as a whole. Some brief comments will aid in establishing these statements, assuming that optimum continuous employment refers to optimum utilization of the labor force during all available work days.

When one considers the crop as a whole, the element of time dominates the problem. There is a "lump of time" between the start of seedbed preparation and harvest. While it is possible to pick out short periods of this time and demonstrate optimum continuous employment in use of labor and equipment during that short period, it is impossible to continue to work on that crop alone under the same conditions of optimum continuous employment during the entire time until crop harvest. Here one must wait upon nature to grow and mature the crop. In fact the farmer seeks to join a minimum of his labor with the fruitfulness of nature in producing the crop. The goal in the "lump of time" for the crop is identical with that for an operation, i. e., to get the necessary work done with the least possible effort. Since the date for completion of certain operations is limited, so that the agronomist speaks of a "critical period" in relation to the calendar time for operations, it is not possible to increase the area of a crop and make a series of continuous "work in progress" operations, so that the entire time of the laborer is used to its optimum continuously, as is the case in industrial production. Such a possibility is conceivable where weather-temperature-moisture conditions are uniform for the entire year.

It is one of the problems of management to organize a farm so that the periods of peak demand for labor at critical periods for individual crops can be staggered by having several crops which are seeded and harvested at different dates. It is seldom possible to reach a condition of optimum continuous employment on a monthly basis, even under the most favorable conditions, although there is room for improvement on most farms.

But another obstacle presents itself when complete utilization of the labor force is sought over time. The weather is an unknown in the calculations. Rain, wind, hail, all occur at unpredictable times. Field work must cease until the weather is favorable, or until the moisture has soaked in or evaporated to a point where the soil can again be worked. This delay causes periods of involuntary unemployment. Some margin of time must be allowed for this situation. Care of livestock, machinery repair and general farm work will of course come in these slack periods.

There is a final obstacle to the goal of year-long optimum continuous employment in field-crop utilization of labor. It is a matter of need for reserves of both time and physical energy for the emergencies, the episodes, the unknowns that occur. If a farm organization could be devised that would furnish complete year-long use of all available labor, the drive from nature's assembly line would be beyond that of any man-made industrial assembly line. Crops would approach maturity with a relentless necessity. Any faltering on the trail and the crop would be lost and with it all the accumulated time and expense of production up to date, nor could anything be done to salvage the crop, since another would be ripening and demanding its full share of labor use. These conditions need recognition in order to stress the purpose of a reserve of time in the planning of any farm organization. Some reserve capacity also seems to be a normal condition in industry.²²

This reserve of time has its practical bearing on the matter of service allowance in estimating crop-labor requirements. A smaller rest allowance can be used in agriculture than in industry because the subsequent period of complete lay-off from crop work allows time for nature to restore the fatigued muscles to their former efficiency. But as one approaches the complete utilization of available time, he must recognize this physical need for recuperation and introduce a larger allowance for rest in the day's work. Another phase of this same problem is seen in the persistence of the 10-hour day on farms. Since so many crop operations must be performed within a comparatively short period of calendar time, it is necessary to work long and hard at these times, and take the needed rest after the rush is over. A factory worker can lay his tools on a bench at the end of an 8-hour day and resume work the next day where he left off. Nature is on a continuous 24-hour shift. When mere man attempts to follow

²² CLARK, COLIN: *The Conditions of Economic Progress*. (New York: Macmillan Co., 1940), p. 62. "In manufacturing production the weighted average percentage utilization of practical capacity in 1925-29 was 80 percent."

her, he must either work alternately at fever heat and then have complete rest, or have an excessive labor force which can be used for only a brief period, then wait for another rush period.

These limitations and qualifications regarding marginal productivity analysis when empiric data are used are reviewed as being significant for all those who contemplate such procedure. Marginal analysis will be most helpful when used in connection with a search for the optimum combination of factors or for the solution of special problems confronting farmers. The equations will assist in both these procedures.

Part V.—THE SELECTION OF CROPS

Equations (1) to (3) can be used as a guide in the selection of crops. The emphasis in the analysis will be on labor inputs without attempting to evaluate them in terms of resulting output. Before any attempt can be made to make a complete marginal productivity analysis using farm data, both the input and the output must be clearly in mind. The writer seeks to stress procedure on the input side, since equations (1) to (3) deal with inputs.

BASIC DATA FOR THE ANALYSIS

The essential information for the use of equations (1) to (3) represents either actual experience on a specific farm as to the speeds, length of field and other values necessary for the variables in the equation or, for purposes of analysis, arbitrary values which must be assigned to these variables. For the purpose of this analysis the writer will rely so far as possible upon common practices reported by cooperating farmers in the northern Colorado irrigated areas. These practices can be analyzed for individual crops.

One seeking the determination of actual field time should start by finding the actual field conditions, i. e., actual length of field, actual width of strip covered by each trip with a machine, a close estimate of the time per turn, and an estimate as to miles per hour for tractor or horse speed. The service time might be broken down into several sub-items. What is needed is an estimate of the probable values. There is no one final answer but there is one estimate which represents the conditions under analysis. To say that all work is done at the same rate of speed, with the same allowance for turns and for the service allowance, is an oversimplifying assumption. Practical farmers will report that all three of these variables change from operation to operation. Actually, the width of machine will vary from farm to

farm, also the effective width, and the times each operation is performed. Also farmers differ in the operations which they use in seedbed preparation. Soils, weedy condition or previous cropping dictate the use of special methods. It is because of these known facts that this theoretical analysis of field labor requirements has been confined, in the first phase, to uniform values for some of these variables in equation (1). With assumed values it is possible to calculate the crew time and the number of hours per acre for these field operations under the existing systems of soil preparation.

CROPS TO BE STUDIED

Barley, corn, potatoes, sugar beets, beans and alfalfa as grown in northern Colorado in the years 1922 to 1933, inclusive, will be analyzed. In these illustrations widths of machines have been assumed as constant in order to reduce the variables.

For each of these crops the typical operations as shown by the detailed studies were selected for analysis. Since during 1922 to 1933 almost all field work was done with horse power, the calculation of estimates was likewise made for horse power. Either 4 or 2 horses were used in the estimates according to past experience for specific operations.

In all cases the calculations were based upon a speed of 2 miles per hour in a field 40 rods long with 1/2 minute per turn and a service allowance of 0.20.

The following tabular summary shows the percentage of the total man labor reported by cooperating farmers for the field operations selected for study or for equivalent work.

TABLE 2.—PERCENTAGE OF TOTAL MAN HOURS STUDIED

Crop	Percentage of total man hours included in specific operations
Barley	35.8
Corn*	38.5
Potatoes	36.6
Sugar beets	46.7
Beans	41.0
Alfalfa	31.7

*Harvesting corn, as reported, actually included many diverse methods amounting to 34.4 percent of the total man labor on corn. Here the writer will use one method of corn harvest, namely, field husking from standing stalks.

It is apparent that from one third to one half the reported man labor is involved in these operations. Much of the balance can be analyzed by other means or is in a form frequently handled on a contract basis. The use of mechanical harvesters will increase the proportion of total time which can be analyzed by the equations. The hours involved in the specific operations are those using the major proportion of power and equipment as shown by the following tabulation for the same crops.

Since power and equipment costs are of increasing significance in American farming, the following summary indicates that the equations can be used in the analysis of an important part of the labor and power costs in crop production. The percentages shown for northern Colorado irrigated farms might differ from those for other areas of the United States where irrigation is unnecessary. With no irrigation, the reduced hours per acre will mean an increased relative importance for the operations under analysis.

TABLE 3.—PERCENTAGE OF TOTAL HORSE HOURS STUDIED

Crop	Percentage of total horse hours included in opera- tions studied
Barley	78.3
Corn	73.4
Potatoes	85.4
Sugar beets	68.6
Beans	69.8
Alfalfa	52.0

The labor-time per acre as shown by the equations will be compared with the actual time as found from field studies. For this purpose the detailed studies during 1922 to 1933 in northern Colorado on irrigated farms using horses as the chief source of power will be used.²³ The following table makes a comparison between the actual data and the calculated labor using horse power for the same operations. In each case the hours for the operations, as calculated under the basic simplifying assumptions for the use of horse power, are compared with the average hours reported in the years 1922-33 by northern Colorado cooperating farmers for similar operations, under all the varying conditions found on these farms. The actual hours include some tractor use, but horses were the main power used during the years 1922 to 1933.

²³ Actual hours from unpublished data for the years 1922 to 1933, Economics and Sociology Section, Colorado Agricultural Experiment Station.

TABLE 4.—COMPARISON BETWEEN CALCULATED AND ACTUAL HOURS PER ACRE

Crop	Calculated hours per acre		Actual hours per acre similar operations*		
	Man	Horse	Man	Horse	Tractor
Corn—after sod	9.98	31.76	11.49	33.31	1.10
Potatoes—after sod	22.24	60.64	21.78	61.26	1.30
Sugar beets—after stubble	14.50	49.92	17.64	48.16	0.25
Beans—after sod	10.85	32.74	13.17	27.53	0.03
Barley—after cultivated crop..	3.85	12.78	4.78	14.93	0.43
Alfalfa	5.40	10.74	4.96	10.06	0.03

*Averages for the years 1922 to 1933.

For each crop the practices which were nearest to "common practice" were selected for the theoretical calculations. The hours actually reported included many different practices, yet the simplifying assumptions of 2-mile speed for horse travel, number of horses in crew, 1/2 minute per turn for all operations, a 40-rod field, a 0.20 service allowance, and machine widths commonly used result in calculated hours per acre which are in close agreement with the actual hours for similar operations indicating that the assumed conditions were close to "average" conditions. The agreement for horse hours seems better than for man hours. The calculated hours are for the assumed homogeneous conditions. The actual hours are for heterogeneous conditions.

The calculated man hours summarized in table 4 vary from 80.4 percent to 108.8 percent of the actual hours, with a simple average for the 6 crops of 90.4 percent of actual. Since the actual hours covered a wide variety of conditions with many different kinds of equipment no one set of assumptions could be expected to represent them all. If a speed of 1.75 miles per hour were used for the calculation, the simple average for the 6 crops would exceed the actual figures by 3.5 percent. If the change was made in A, then A should have a value of 0.35 in order for the calculations to be approximately equivalent to the actual hours. Fields on these farms varied from 25 to 158 rods long. The 40-rod length used in the calculations is below average. If 80 rods were used, speeds slower than 2 miles per hour and an A larger than 0.20 would be necessary in order to secure calculations which agreed with the actual hours. For example, in an 80-rod field horse speeds of 1.75 with an A value of 0.238 would result in calculations almost identical with the actual hours for the 6 crops. These calculations merely indicate the flexibility in analysis made possible by means of the equations.

VARIABILITY IN LABOR REQUIREMENTS

The arbitrary values assigned to the variables in equation (1) for the operations listed for the 6 crops have given hours per acre which compare favorably with the 11-year average on the actual farms for similar operations. But how about these farms? Were the farmers' reports as to labor per acre consistent? Was there any relation between labor applied per acre and the output of crops? Two examples will offer some evidence. Hours of contract labor were not included in either case. For the 10 years, 1922 to 1931, there were men who each year were able to produce sugar beets and potatoes with (a) much less than average per acre labor requirements, or (b) much more. A simple average for these "low-requirement" men producing sugar beets gave the following results: 26.3 man hours, 55.2 horse hours, and 0.7 tractor use per acre. With this labor these men produced 15.1 tons of sugar beets per acre; while for the "high-requirement" men, 59.1 man hours, 88.8 horse hours, and a "trace" of tractor use produced 13.8 tons of sugar beets per acre. Some or all of the variables under study, plus the management ability of the operator in organizing his year's operations, would emerge if time were taken to trace these data to their individual causes. These two groups of producers are cited as indicating that the actual or anticipated conditions on an individual farm must be the starting point for any constructive analysis of labor requirements.

Potatoes during the same years offer the following contrasts: 34.5 man hours, 62.2 horse hours, and 1.3 tractor hours produced 8,692 pounds of field-run potatoes per acre as an average for the low-labor-requirement men. The high-labor-requirement men needed 83 man hours, 78 horse hours, and 1.0 tractor hours per acre to produce 13,419 pounds of potatoes. Since hours for hauling, cellar sorting, and marketing represent an important part of the labor on potatoes, it is apparent that yield has had an effect upon total labor requirements in this instance. The only labor on sugar beets directly related to yield was the hauling from field to beet dump. Here again the variables on individual farms loom large in any discussion of labor requirements, yet they are concealed in "average labor requirements."

To summarize for sugar beets, 26.3 man hours per acre for the low group compare with 59.1 man hours for the high-labor group. For potatoes 34.5 man hours for the low group compare with 83 man hours for the high-labor group. Both of these classifications are included in the averages shown on page 35. It is apparent that the individual farmer will have conditions that differ from any average of mass data. The equations will give

such an individual a method for studying his own crop labor requirements.

THE EFFECT OF TRACTOR POWER UPON LABOR REQUIREMENTS

The above discussion of calculated hours per acre was based upon the assumption of uniform conditions for the use of horse power. The effect of substituting tractor power will depend upon how the tractor is used. In the following table by the use of equation (1) estimates have been made for three crops, using the identical operations, width of machine, times over and length of field which were used for the calculations summarized in table 4. The only differences are in the use of several speeds for the different operations and a value of 0.35 for A when tractor speed was $3 \frac{1}{4}$ miles per hour and 0.25 for all other speeds. This larger allowance is designed to cover the need for longer rest periods when driving a tractor, and to offset the tendency for tractor wheels to slip, thus reducing the gear speed.

Any change in the conditions as stated would result in a change in the necessary hours per acre. For example, the use of 20-inch sugar-beet rows would add 0.71 hour per acre to the 12.58 hours shown for all operations in table 5. If the field was only 20 rods long instead of 40 rods it would add 1.66 hours per acre to the 12.58.

Likewise a change in the width of machine, or in the number of times the operation was performed would change the hours required for that operation.

The 12.75 hours for potatoes cannot be compared directly with the 22.24 man hours for potatoes in table 4 since 6.02 man hours cutting potato seed were included in the 22.24 hours.

The presence of all these possibilities makes it important for farmers to seek the methods that will do the work in a minimum of time. Extra hours per acre may mean additional costs per acre without any increase in production.

TABLE 5.—CALCULATED HOURS PER ACRE, TRACTOR POWER
(For same operations summarized in Table 4)

Crop	Width of machine	Speed	Times over	Crew hours for operation
(a) SUGAR BEETS				
Disk before plow	6 ft.	3 1/4 mi.	1	.69
Plow	16 in.	2 1/2	1	3.62
Spike harrow	15 ft.	3 1/4	2	.56
Float	10 ft.	3 1/4	1	.41
Spike harrow	15 ft.	3 1/4	1	.28
Plant 4-R	88 in.	2 1/2	1	.66
Cultivate	88 in.	1 1/2	2	2.06
Reditch	88 in.	3 1/4	1	.58
Pull	22 in.	2	1	3.72
Total crew hours for these operations				12.58
(b) POTATOES				
Plow	16 in.	2 1/2	1	3.62
Spike harrow	15 ft.	3 1/4	3	.84
Float	10 ft.	3 1/4	1	.41
Plant	34 in.	2	1	2.07
Harrow after plant	15 ft.	3 1/4	1	.28
Cultivate	34 in.	2 1/2	1	1.70
Reditch	68 in.	2 1/2	2	1.70
Dig	34 in.	2	1	2.07
Total crew hours for these operations				12.75
(c) BEANS				
Plow	16 in.	2 1/2	1	3.62
Spike harrow	15 ft.	3 1/4	2	.56
Float	10 ft.	3 1/4	1	.41
Plant 4-R	96 in.	2 1/2	1	.60
Harrow after plant	15 ft.	3 1/4	1	.28
Cultivate	96 in.	2 1/2	2	1.20
Reditch	96 in.	2 1/2	2	1.20
Cut	48 in.	2 1/2	1	1.20
Total crew hours for these operations				9.07

CHOICE BETWEEN COMPETITIVE CROPS

Labor requirements are not the only item of cost to be considered in making a choice between competing crops, yet at certain times of the year labor becomes an important item.

Assume for the moment that the problem is the choice of one among several crops which are directly competitive for use of man labor at critical periods during the growing season, and for similar positions in a cropping system. Assume likewise that the labor and other resources are available. This means that contract labor typically employed for certain operations can be secured when needed.

Choice of a cereal crop.—The simplest case would be a choice among cereals—barley, oats, or spring wheat. Other considerations such as adaptation of the specific crop for use as a nurse crop for grass or alfalfa seeding, for adaptation to the feeding of specific kinds of livestock or as human food must weigh in

the final decision but, for the moment, they can be ignored. Local experience will suggest that these crops are approximately identical in their requirements for seedbed preparation on similar soils when grown in a given spot in the crop rotation. Hence the cost of seed, the cost of threshing, and the probable production rather than the labor requirements are the determining factors in choice as long as the other factors are assumed favorable. None of these items come within the scope of the equations. The usefulness of the equations will appear after the cereal is selected. The equations will supply a means for anticipating the labor requirements for the operations to be done. They will aid in fitting cereal production into a season-long use of available labor resources.

Choice of a cultivated crop.—A more complicated case involves the choice between competing crops, such as corn, sugar beets, beans, and potatoes. In this case the conflict for use of man labor is not continuous for the entire growing season. Using northern Colorado irrigation farming as a basis of comparison, sugar beets may be planted before spring work is started on corn or potatoes. However, in the absence of sugar beets, the seedbed could be prepared for these other crops at an earlier date. Also at harvest, beans may be threshed before corn, sugar beets, or potatoes are mature. In spite of all these modifications, for the season as a whole, the area of one of these crops grown on a specific farm reduces the area that this farmer can grow of the other crops.

Sugar beets, beans, and corn may be used for analysis. With the previous discussion in mind, assume that the man labor and power of the farmer and his regular laborers are involved, i. e., that contract labor can be had as needed for special operations. The first comparison will be for conditions on northern Colorado irrigated farms using horse power, as just discussed. In round numbers the calculations on page 35 show that corn required, up to harvest but not including irrigation hours, 10 man and 32 horse hours per acre; beans 11 man and 33 horse hours, including cutting, and sugar beets, 14 man and 50 horse hours, including pulling but not including any hauling. For each of these crops the summer irrigation is done typically by a regular employee, but the use of water varies. Sugar beets require "late reservoir" water which in northern Colorado is expensive water, while corn can be matured by the use of "early direct-run water," which is less expensive. Here is an outside limiting factor which might upset any choice made in ignorance of this condition. In fact, where water is the critical factor, one can assume that 2 acres

of corn can be grown with the water needed for 1 acre of sugar beets. The hours of man labor in irrigation are likewise approximately in this inverse ratio, i. e., 1 hour on corn vs. 2 hours on beets.

Of the three crops, beans are the most uncertain as to probable yield since they are somewhat more susceptible to various plant diseases and insect pests. When conditions are favorable, yields of better than 40 bushels of beans are common; at the other extreme, 10 bushel-yields or even less are frequent. Sugar-beet yields typically have been the most consistent, especially over large areas, yet 2 consecutive years on the farms studied have shown yields with a 2-to-1 ratio. It is apparent that the final decision as to a crop will depend upon a careful study of all these conditions—labor supply, water supply, prospective price, probable yield, as well as total costs, and the farmer's past experience with the crop.

If the farmer's regular man labor is the limiting factor and irrigation requirements are included, about 16 acres of corn or 14 acres of beans can be grown with the regular labor required for every 10 acres of sugar beets if horse power is used.

SEASONAL VS. SPECIFIC OPERATION LABOR ANALYSIS

This overall or seasonal basis for comparing the areas of specific crops, with "total field hours per crop acre" as a guide, raises the following questions in regard to its adequacy: (a) What assurance can be given that a shift from one crop to another can be made with no disturbance of the balance between available and required labor? and (b) are the peaks of demand for man labor identical or interchangeable between sugar beets, potatoes, beans and corn? The implication behind these questions is that each specific operation on a crop must be done within a specific calendar period of time, usually within a very limited period of calendar time.

PLANTING DATES

Planting in northern Colorado during the years 1924-34, inclusive, was done within the following dates: (a) Sugar beets were planted between March 17 and July 9, a lapsed period of 85 days. Typically the planting was done between April 12 and April 26, a lapsed period of 15 days, all prior to the normal planting date for beans or potatoes. (b) Potatoes were planted between May 5 and July 8, a lapsed period of 64 days. Typically the planting was done between June 1 and June 10, a lapsed period of 10 days. (c) Beans were planted between May 5 and June 26, a lapsed

period of 52 days. Typically the planting was done between May 27 and June 1, a lapsed period of 6 days, all prior to the normal planting date for potatoes.

These variations in dates arose from weather, soil, or other conditions. Obviously farmers seek to plant at the most favorable date, but they actually plant when they get to it, even beyond the optimum date.

The point which should be stressed is the comparatively long period within which planting is done—15 days for sugar beets, 10 days for potatoes, and 6 days for beans. This accounts for 31 days of the 60 days from April 12 to June 10, inclusive. Corn planting data were not analyzed for this period but ample time for corn planting would seem to be available between the sugar beet and bean planting dates.

From the theoretical calculations, using horses, planting an acre required (a) 0.76 crew hour for sugar beets, (b) 1.99 crew hours for potatoes, (c) 0.71 hour for beans, and (d) 0.94 crew hour for corn, with 10 hours as the working day. If 80 percent of the lapsed time could be assumed, and the balance held as a reserve against weather and other hazards, then a net period of 120 hours for sugar beets, (i. e., 80 percent of the 15-day 10-hour day normal planting period,) 80 hours for potatoes, and 48 hours for beans would, with the above crew hours and horse power, give one man time to plant 158 acres of sugar beets, or 40 acres of potatoes, or 67 acres of beans. These areas do not include the possibility of working beyond the dates for typical operations. If this extension were allowed the areas could be increased materially.

This comparison suggests that the substitution of one crop for another within the typical period for planting will not involve any serious strain on the available labor supply during planting nor require that work be done at dates which are outside those normally used for planting.

HARVESTING DATES

Harvesting is typically used as an example of the real bottleneck in crop production. Reference to the northern Colorado date for 1924-33, inclusive, revealed the following information: Beans were cut typically between September 13 and 17, a lapsed period of 5 days. Since the years 1922 to 1933 early maturing varieties of beans have been introduced which can be harvested 2 to 3 weeks earlier. Potatoes were dug typically between September 29 and October 15, a lapsed period of 17 days. Sugar beets

were pulled typically between October 8 and November 6, a lapsed period of 30 days, 8 of which were in direct conflict with the potato harvest. The over-all period for the harvest of these three crops, i. e., from September 13 to November 6, was 54 days. Actually in the 1940's beans were harvested before the September 13th date, thus extending the 54 days by at least 3 weeks.

Using the theoretical calculations, the crew time per acre for the farmer's own time for these harvesting operations was for horse power: Beans, 1.4 hours, potatoes, 1.99 hours, and sugar beets, 4.62 hours. Assuming again that 80 percent of the lapsed time could be used for field work, this means that with horse power, and deducting the conflicting days from the sugar-beet harvest period, 28.6 acres of beans, 68.3 acres of potatoes, and 38.1 acres of sugar beets could be harvested within the 54-day harvest period, assuming full time of one crew at these respective operations for 80 percent of the typical period for each and assuming that hand contract labor and hauling were available. These total to 135 acres.

These total acres of the three crops compare to 265 acres of the three crops which could be planted if the same "full-time devotion to duty" was assumed with horse power in the 60-day lapsed period at planting. Apparently harvesting is the limiting factor as to possible acreage for these crops.

It is apparent from these two illustrations, together with the fact that typical farms have about 160 total acres, that the actual time required for any one operation taken by itself is not the critical limiting factor in determining the area of any specific crop which can be grown in northern Colorado. The limitations arise (a) from all operations, since other crops require some other operations at approximately the same time that any specific operation is being done on one crop; (b) from the limitations imposed upon the area of one crop arising from the necessity of organizing an effective cropping system as a whole; (c) from the limitations of field areas or of farm area as a whole; or (d) from limitations imposed by the weather and other unknowns.

Changes in current practices, tractor power, current wages, and other changes should be followed by one making this type of comparison to guide future decisions. In the absence of published cost studies this will be a difficult matter for those who do not have some method for estimating comparative labor requirements. Equations (1) to (3) offer such a method for the field labor part of the labor needed. Current cost rates are typically the easiest to secure; crew hours per acre are the most difficult.

If two crops are competitive in their use of labor, and in their location in the cropping system, the contrast between the labor requirements and value of product will supply data for use to guide in a choice between them. There is one point, however, which may prove conclusive in the short run. If the new crop requires machinery which the farmer does not own, he may be unable to buy this machinery, even if all other evidence indicates that he should make the shift in crops. Also, the crop to be dropped may require machinery which is not useful for any other crop, and not easily salable. Hence the shift in crops will involve loss of this investment. If the advantage in the shift over a period of years seems sufficiently profitable to pay for this sunk investment, then it will be desirable; otherwise, a change might be delayed till this special equipment was nearly worn out and new purchases needed.

CHOICE OF A CROP AS A SUPPLEMENT TO THE MAIN CROP

This problem introduces a characteristic of farming which differs radically from industrial conditions. In factory production, typically, nothing is produced unless men are hired and paid specifically for this production. On farms the owner is there "by the year;" his regular help is hired "by the month." Hours per day or pay per hour are not the key terms in farm-labor analysis under such conditions. Nature has a time schedule or assembly line of her own. This characteristic of farming has been discussed in part IV but now its significance is evident. The farmer has the labor, the horse power, the machinery, and he finds some idle time on his hands between periods of work on his major crops. Assume that he is fully employed, or expects to be when these major crops require labor. Then he is faced with the problem of salvaging some of this idle time. What extra expenses will he have if he tries to salvage this time? What crops can he select to help salvage this idle time? The most common example of this is the oat crop. With horse power, the out-of-pocket extra costs will be for oat seed, for seeding equipment, for harvesting equipment and expense, together with the "land expenses," namely, taxes, water, and depreciation.

The equations will aid in calculating the hours required per acre, hence in estimating how many acres can be safely added to the present cropping system under a given set of conditions. The man hours required per acre for seedbed preparation and planting spring grain are so low that other considerations will typically control the final decision as to the area to be grown.

THE MARGINAL METHOD FOR FARM AS A WHOLE

This analysis should be in pecuniary terms to be significant. The 1922-33 records indicate that the expense of seed, twine, threshing, water, and real-estate tax were approximately \$10.00 per acre for oats. The oat yield on these farms was 66.6 bushels or 2,132 pounds. The price over this period was \$1.27 per hundredweight or \$27.08 per acre. This leaves \$17.00 per acre of oats to help pay for the labor already engaged by the month, for interest on the investment per acre in the land, and for the cost of special equipment used by the oats. Faced with this analysis most farmers would grow oats. If all labor of men, horses and equipment were assigned to oats at "going rates," an entirely different conclusion would be reached. The first method is the road to increased total income from the farm. The second is sound, according to customary complete cost account analysis. Current costs, yields and prices should be used to make this decision applicable to current needs. Here one is concerned with the procedure, not with the specific detail. This case is one instance where marginal analysis points to sound conclusions whereas complete cost analysis hides the significant facts in a maze of detail and sinks the correct conclusion by means of joint cost distribution technique.

Part VI.—THE EQUATIONS AND MARGINAL ANALYSIS AS AIDS IN SOLVING SPECIAL PROBLEMS

The business farmer is continually faced with the necessity for making decisions regarding conditions which affect his income. He wishes to know how and where to use labor, land and materials to the best advantage. What can equations (1) to (3) offer the farmer in this situation? Several cases will be considered.

USE OF SURPLUS LABOR

Assume that the farmer has determined the optimum combination of labor, materials and land in the production of a given crop. Shall he add more labor to the same area of this crop or use an assumed surplus of labor on additional acres? On page 27 it was concluded that, "Once the optimum selection of operations . . . have been agreed upon, there are few farmers who would care to . . . make work by doing extra operations." This statement resulted from detailed review of the conditions surrounding development of this assumed optimum method of production. It would be idle to start from any other base. Search should be directed toward the discovery and adoption of these optimum

methods of crop production for each crop rather than toward the testing of the effects of a little more added to the optimum. Optimums should likewise mean that laborers were skilled in the specific operations. Cases are on record where inexperienced labor for one critical operation caused a one-third reduction in final yield because of their low capacity to use power, equipment or materials.

With the optimum methods assumed, there remains the question as to the best use of the surplus labor or materials. This reserve of labor, considered as remaining after all cropping operation adjustments have been made, must be of two possible kinds: (a) Available at periods of low demand for labor on the farmer's original crops or (b) a general excess of labor throughout the entire growing season. If the first condition exists there may be no crop which will use labor to advantage at these specific calendar dates. In that case the farmer must look to other parts of his business for employment. There are many items of general farm improvement and repair on which labor can be used in these slack times. Such operations are outside the field covered by the equations.

If the second condition exists, the farmer apparently operates too small a farm for full use of his existing resources of labor and materials. He should seek additional acreage and expand his entire cropping system, since each crop under the assumptions is being produced under optimum conditions in the use of labor and on an optimum comparative area relative to the other crops in his cropping system. This introduces the problem of finding the limit of size of farm and the quantity of other factors of production which this farmer has the capacity to manage. This is in general a question of the executive ability of the individual farmer. The questions can be used to test the labor requirements for the operation of any new areas. New conditions will arise, either involving some waste in time in going between two farm areas not contiguous, or involving a change in field layout which will change former experience in time required per acre for specific operations due to such matters as length of field, distance of field from farmstead with larger service allowance in the equation, or other items. If a review of these conditions shows that yields in excess of previous experience would be necessary to justify the added expense, then the farmer should seek other methods of expanding his scale of operations. The phrase "added expense" is used because farms typically can be leased or purchased as a unit, not an acre at a time. Hence the farmer may have some surplus labor on his

farm, but when he seeks to use it by acquiring control of a second farm, this new area will seldom be just enough to absorb existing surpluses of labor.

RESULTS FROM CHANGING FARM SIZE

An expansion in farm size for the individual operator typically means the acquisition of some other farm. The farmer seldom finds it possible to add an acre at a time. The expansion will be made by adding several acres at a time. This means making discontinuous changes which are far removed from the ideal infinitely small increments of change that are assumed in marginal productivity analysis.

Reference to a specific case will show the problem. A tenant farmer operating 148.4 acres of crops on the original farm added 27.5 acres from a nearby farm. His increased cash farm expenses were \$61.40 per acre for the 27.5 acres compared to \$20.79 per acre on the 148.4 acres of all crops the previous year, while his added cash receipts were only \$41.67 per acre on the new 27.5 acres. Before he had time to consider the implications of this adventure, crop prices took an upward turn so he continued to operate the new additional area for several years. Then a new crop appeared and he leased 16.5 acres more from this second farm in order to take advantage of the possibilities from this new crop. This increase in crop acreage involved shifts in the area of several crops on his original farm. The results from the second increase in total crop acres gave \$74.21 added costs per acre for the extra 16.5 acres, while added cash receipts were \$216.96 per acre. The resulting net income was so favorable that the following year he rented 139.1 additional acres from the second farm. The result was only \$36.75 increased costs per acre for the 139.1 acres, while increased revenues were \$51.36 per acre for the additional 139.1 acres. As a consequence the owner of the second farm rented out the remaining crop land of his entire farm to this operator. This final 38.4 acres of crops then caused added cash costs the next year of \$61.05 per acre while the additional revenue from the final 38.4 acres was a minus \$28.78 per acre for the 38.4 acres. In spite of this unfavorable effect of the final increase the farmer continued to rent the entire second farm because the net income from the entire acreage was satisfactory.

This case has been reviewed because it has one unusual condition—the owner of the second farm was in the market for a tenant and was willing to release part of his farm each year in the hope of securing this farmer as the tenant for the entire farm. The data as used were from the actual record, but one

must not ignore the confusing effects of prices and yields as they varied from year to year.

Now to come back to the original problem, namely, how to use surplus labor. This farmer solved it by experimenting with added areas rather than adding labor to his original area. His final results were increased net revenues, but at the expense of a higher level of average costs. He did not meet the test of "optimum use of resources" although he made better use of his own management abilities.

The problem can be approached from other angles, namely, a comparison between the relative marginal productivity of labor applied to several crops with the objective of expanding the use of labor on those crops which produce the largest amounts of human food per unit of labor. The difficulty with this approach lies in the fact that (a) it rapidly gets away from economic considerations and delves into non-economic territory dealing with nutrition, human likes and dislikes in regard to foods or crops; and (b) it soon trips on the fundamental farm management problem of a balanced cropping system needed (1) to maintain soil fertility, (2) to secure a fairly uniform distribution of labor on all crops throughout the entire growing season, and (3) to feed the livestock used for power, or to provide human food.

These conditions are not rigid on a given farm, but neither are they completely flexible. There is, typically, a cropping system that is superior to others for a given farm. Once this system is found the equations can aid in the selection of competing crops for specific spots in the cropping system or in the selection of supplementary crops to use available resources at slack times. These methods have been reviewed in the preceding pages.

LIMITATIONS IN USE OF MARGINAL PRODUCTIVITY ANALYSIS

One point, however, needs further emphasis. This problem of continuous use of labor throughout the growing season has an implication which is easily ignored. It is the key to some current differences of opinion. The farmer can never lose sight of this year-long use of labor. Therefore he seldom can concentrate on any one crop. To do so would throw his cropping system out of balance. The labor aspects are stressed here, but the fertility aspects and the need for a change in crop on a specific field to overcome baffling problems of pest and disease are equally important. Production of field crops for winter feeding and the use of nurse crops for the seeding of alfalfa and grasses must also be considered by the farmer.

Because of these conditions a farmer may find it unwise to expand the area of a specially profitable crop to the limits indicated by pure marginal productivity theory. He will stop, in fact, far short of the marginal limits of profitability in order to keep his cropping system as a whole in balance.

A METHOD FOR ANALYZING SALVAGE OPERATIONS

There are, however, many specific management problems that arise during the cropping season which present an opportunity for analysis either by the use of equations (1) to (3) or by marginal productivity analysis. For example, it has been shown by technologists that a delay at seeding results in a reduction in the final yield of many crops. Assume that with normal planting dates the value of the crop will be sufficient to exceed all costs by \$5.00 per acre. With each day's delay in planting the yield is reduced until a delay of 14 days results in a crop which does not pay all costs of production; further delays in planting result in greater financial losses. The farmer is interested in some method for preventing these reductions in yield.

This is the theory of the relationship. To translate it into everyday terms requires data from technological crop students, and additional data as to the salvage operations which must be performed. The additional costs may be no more than the securing of extra labor and power for 24-hour operation to speed up seeding operations after a late, wet spring, in which case they can be found from local experience and their cost estimated by use of equation (1) to show the additional hours required. In the absence of this "additional cost" the seeding would be delayed until the regular labor force could do the work.

For example, Leonard and others²⁴ report that a delay in planting corn from April 20 to June 10 caused the average corn yield to fall from 53.3 bushels per acre to 30.9, or a 22.4-bushel reduction. Seeding at May 20 gave 45.7 bushels or a 7.6-bushel reduction. A delay in seeding from May 20 to June 10 reduced the yield by 14.8 bushels, while a delay of 30 days from April 20 to May 20 resulted in only a 7.6-bushel loss in production. Obviously, approximately twice the added expense would be justified to avoid the 21-day delay in comparison to that justified to avoid the earlier 30-day delay.

There are reductions in yield which result from poor management in the selection of a time for the operation, such cases, for example, as fall plowing vs. spring plowing or manure plowed

²⁴ LEONARD, WARREN H., BRANDON, J. F., and CURTIS, J. J., *Corn Production in Colorado*, Colorado Experiment Station Bulletin 463 (December, 1940), 38 pp. ill. p. 23

under in the fall vs. manure plowed under in the spring. Since these examples come under the category of "good business ability" they do not come within the range of (a) marginal productivity analysis or (b) the equations. They do stress the necessity for use of optimum conditions before any significance can be attached to a study of intensity of culture or of use of added hours of labor.

CHOICE OF A METHOD OF HARVESTING WHEN PRICES FALL

A salvage operation of a slightly different type presents itself at harvest. Assume that a potato crop has been grown, but that the price at harvest time has fallen to 25 cents per hundredweight. This is far below the expenses already incurred. Shall the crop be abandoned? Shall hogs be turned in to root up some feed? Shall the potatoes be "plowed out" and livestock turned in to feed? Shall the potatoes be dug and fed to livestock?

Here one needs specific information (a) as to the comparative additional costs for each of these possibilities, and (b) as to the probable returns from each. For the sale at prevailing market prices there is already a basis for estimating the probable returns. The costs may be analyzed as follows: What is the cost of digging potatoes? Equation (1) can be used to estimate the crew hours for digging potatoes under the given conditions. Prevailing rates for man labor, horses or tractors can be used to translate these hours into per acre costs. Picking, hauling, and potato sacks, if used, can likewise be estimated on a unit basis, per bushel or per hundredweight. The probable yield can be estimated quite accurately by sampling the yield from a few spots in the field. Assume the yield to be 100 hundredweight. Assume that the digging will take 1.5 hours for man and tractor or \$1.20 per acre when the rates are 30 cents per hour for man and 50 cents per hour for tractor. This is equivalent to 1.2 cents per hundredweight. Assume that potato picking will cost 7 cents per hundredweight, and that hauling to market will cost 5 cents per hundredweight. These individual items amount to a total of 13.2 cents per hundredweight in bulk. If sacks cost 6.8 cents each, the potatoes can be delivered for 20 cents and sold for 25 cents, leaving 5 cents to apply on the sunk costs prior to harvest. This is not a rosy picture, but the \$5.00 per acre thus salvaged from 100 hundredweight is better than doing nothing, meanwhile all additional costs have been paid. These rates have been used for illustrative purposes and are not representative.

Before deciding on marketing the potatoes, one should consider the value of the crop for stock feed. Apparently under the

assumed conditions it will cost 8.2 cents per hundredweight to dig and pick the potatoes, probably a few cents more to haul them to a feedlot. Here one needs information on the feeding value of potatoes for the available livestock as compared to customary feeds. Also one needs to know the cost of storing these potatoes and feeding them during several months of the feeding period and whether the labor is available to do this feeding. Again, these are matters beyond the immediate scope of the inquiry, so they will be omitted. Apparently 100 pounds of potatoes have a livestock-feed value approximately 22 percent of that for 100 pounds of corn which, with corn at \$1.65 per hundredweight, would mean 37 cents feeding value for the potatoes as compared to the market price of 25 cents.

CROP SUBSTITUTION AS A SALVAGE OPERATION

Again one may assume that sugar beets are planted but that dry weather has delayed germination until May 25. Shall the farmer attempt to go through with a sugar beet crop or shall he plant some other crop such as beans? If he abandons the sugar beets and plants beans the labor already done can be substituted for normal seedbed preparation for beans and thus the seed and the planting are the only new costs. If he continues with the sugar beets he must assume the risk of a crop "normally planted as of May 25," since the seed has been dormant from the actual date of planting till May 25.

Here one must rely upon technological data as to the influence of date of seeding upon sugar-beet production. There are two possibilities: (a) The analysis can be in terms of "beet yield lost" by the late planting or (b) in terms of the beet yield expected from the late planting. Either of these can be compared to the prospective yield from the alternative crop of beans. Uncertainty enters the picture here. "Plow it up," said a neighbor, and 17 tons of sugar beets per acre resulted from failure to follow this advice in one case, while only 10 tons resulted in another case not over 100 rods from the first field in the same year, due to variation in soil conditions.

Experiments in 1938 and 1939²⁵ show a reduction of 4.8 tons yield of sugar beets where seeding was delayed 3 weeks. This lower yield represents a reduced value per acre which typically exceeds the per acre "profits" from sugar-beet production. The sugar beets at this late date of planting can offer, under this assumption, no more than a "break even" result at the best. What about the prospects for beans? In northern Colorado, May

²⁵ Unpublished data from Sugar Beet Investigations at the Colorado Agricultural Experiment Station.

25 is the normal planting date for beans. No expenses will be needed for seedbed preparation for the beans, which represents normally 5.5 man and 22.2 horse hours, if horse power is used, or 4.1 crew hours with tractor power. Hence, beans planted on the abandoned sugar-beet land would have lower specific costs.

The fact that drought has delayed germination should be included in the analysis. The drought should result in a lack of water for late irrigation of the sugar beets. Drought, incidentally, suggests a dry atmosphere for the growing season, which is a favorable condition for bean production under irrigation. If soil and other conditions are favorable for beans, a normal crop may be anticipated. This possibility should be compared with the reduced yield of sugar beets and the lower sugar content which will normally be expected from the late germination of seed. Values need to be estimated for each part of this comparison, but the bare outline strongly suggests that the farmer should consider the matter carefully before he decides to continue with the sugar-beet crop at this late date. This analysis differs from the discussion on page 48 where it was assumed that the effects of late seeding could be offset by some special operations. This assumption is not valid at this point.

OTHER SALVAGE OPERATIONS

These cases (a) where special operations can offset the anticipated reduction in yield and returns due to some delay at a critical period in plant growth, delayed planting being used as the special case, and (b) where substitute crops are planted, have offered the basic procedure which should be followed at any point in the season. The choice facing the farmer after rainy weather has allowed weeds to gain control of a cultivated crop will be to (a) abandon the crop, (b) plant a new crop after plowing under the weeds, or (c) try to remove the weeds and salvage the crop. The procedure in cases (b) and (c) can be identical with those just reviewed for delayed planting. Case (a) assumes that no other crop offers hope of revenue in excess of the special costs involved, or that salvage operations would come under the limiting condition where the marginal costs would be greater than the marginal returns. There may be in this case another possibility. Livestock may be secured to graze on the weeds, thus turning waste into net livestock gains. Since livestock gains from "pasture" are typically the lowest cost livestock gains, this may be the most desirable solution. Here one needs data as to livestock gains under similar conditions.

POSSIBLE ECONOMIES FROM REDUCING THE MAN HOURS PER OPERATION

Typically, farmers pay their regular workers by the month. Reductions in hours per acre of crops will mean, at first, a reduction in the hours worked per month. If no other work is supplied or no additional acres operated, this reduction in hours per month will mean a higher cost per hour worked. Hence the "saving" of time will not mean any lower per acre cost. Rates per hour actually worked would increase in proportion as the hours decreased, because the monthly wage will be distributed over fewer hours per month.

Hourly rates increase because these savings of man labor per crop acre actually occur as a series of small reductions on specific operations scattered throughout the year, none of which are of sufficient importance to make it possible to reduce the labor force at the moment. These reductions will permit shorter work days or increase the possibility of completing an operation during the most favorable soil moisture conditions, thus transferring the hours for this operation from a less desirable to a more desirable position on the calendar. In this case a possible increased yield per acre may compensate for the increased cost per hour of labor.

ANALYZING THE EFFICIENCY OF INDIVIDUAL WORKERS

Farmers commonly recognize that hired men are seldom paid in proportion to superior output, but rather in relation to typical rates of pay in the community. The question may be asked, "How much more can one afford to pay the superior workman?" Equation (2) will prove useful in analyzing this question. A farmer can determine the typical rate of travel for the superior man in contrast to other workmen; he can note the time required for turning at the end of the field; he can estimate the service and rest percentage.

Actual observation on a specific case obviously is required, but the method can be demonstrated by arbitrary assumptions. If two workmen, A and B, are for hire and information is available as to their rates of operation, values can be substituted in equation (2). Let one assume that A has shown the ability to drive a team of horses at a speed of 2.5 miles per hour, that he uses $1/2$ minute for turns, and that he needs a service allowance of 0.20. The length of field is not involved nor is the width of machine, since presumably these would be the same for either workman. Assume a 10-rod length of field. Using equation (2) this results in a value of 6.67 for C.

If B has proved less efficient, past experience may show speeds of only 1.75 miles per hour for teams that he uses. He may need $3/4$ of a minute to turn around at the end of the field. He may need a service and rest allowance of 0.25. Under these conditions, equation (2) will give a value of 10.02 for C in a 10-rod field. Obviously, a change in length of field will cause the value of C to differ for both A and B.

The 10.02 is 150 percent of 6.67. It will be remembered that C, as found in equation (2), can be used in equation (3) to determine the hours per acre for any specific width of farm equipment, assuming that all other conditions remain constant. Hence with a 6-foot machine, workman A can cover 1 acre in 1.11 hours, while workman B will require 1.67 hours. If sufficient decimals are used, it will be found that workman B uses 150 percent of the hours per acre needed by workman A. Or, in reverse, workman A can do the work in two thirds the time required by workman B, or cover 150 percent of the area that B can handle.

The ability to handle 4 horses in place of 2 horses is one phase of the individual capacity of men. Farm laborers vary in their capacity to use other factors of production. This capacity in turn places a limit on attempts to expand output by increasing the responsibilities of individual workers. These individual capacities of both farm operators and farm workers will at times prevent the smooth working of theory in the application of methods for expanding the scale of operations.

EFFECTS OF SEASONAL PRODUCTION UPON RATE OF RETURN

Seasonal products have other aspects than mere "cost and price" relationships. It has been customary to use opportunity costs as a measure of "cost" for use of resources for each short period of time. Yet seasonal products may exist under conditions where it is not easy to find other employment for the balance of the year. Where this is the case, earnings for the given productive season must be at a rate sufficient to hold the resource continuously. For example, a summer resort may have a 2-month season. The capital will be idle for 10 months. Earnings for the 2 months must compare with earnings on other uses of capital or no one will build summer resort facilities.

It would be idle calculation to compare "alternative opportunities" and rates of return for the summer resort for 2 months and expand such facilities until earnings for the 2 months were at normal yearly rates. If the yearly rate was 6 percent, 1 percent in 2 months would be at this yearly rate. The contrast

should be with yearly rates, i. e., 6 percent for each. Where perfect mobility of factors exists, this restriction is not needed. Actually mobility is somewhere between these extremes. Take the case of a farmer producing a specialized product, and unable to find other employment for the balance of the year. Assume a 5-months production period for the crop and 3 months full employment of labor during the 5 months. If the farmer has no other income, then his labor earnings from this crop must be four times the going rate for the hours actually employed before he can survive from such employment. If other employment can be found for another 3 months, this cuts the necessary earnings for the 6 months to twice the going rate. Few have considered this angle of specialization as a farm management problem and many farmers have worked at less than a "living wage" because of their failure to see the situation in its true light. This does not consider the case of the part-time farmer who uses the farm as a home and as a place to produce some of his own food while he earns his main income elsewhere.

GENERAL ANALYSIS OF SPECIFIC PROBLEMS

The problems facing the individual farmer are literally endless. The examples discussed are taken from past experience. Possibly enough has been said to justify a concluding comment. Equations (1) to (3) and the marginal productivity method of analysis, taken together, offer valuable tools for attacking these problems. The increased accuracy from the use of more exact methods of estimation will widen the areas over which such judgments can be made, and may assist in removing some of the mysticism from "management ability."

As suggested in part V, the basis for any analysis of the efficiency of agriculture should start with the analysis of individual operations. Then alternative choices of crops for a given place in the rotation should be made. At all times the results should be compared with the available year-long resources before any change is made in one place in the rotation only to find that it has resulted in increased idleness in the use of resources at another place in the rotation.

THE SIGNIFICANCE OF INDIVIDUAL MANAGEMENT ABILITY

Analysis of variables which affect labor requirements or net returns and the discussion of problems requiring action by farm operators would be incomplete without including the most significant resource on the entire farm, namely, the management ability of the farmer. This is treading on delicate ground, since every man is supreme in his own eyes, not inclined to thank one

who implies otherwise. One may approach the discussion from the point of view which in days of labor shortage might be suggested as ideal for the use of any resource, namely, full employment of that resource at the task for which it is best adapted and in such combination with other resources that optimum use is made of the specific resource under scrutiny. This goal may be applied to land, to investment of capital in farm improvements, and to the use of labor, livestock and machinery. Here one should consider it as related to management ability. Some may prefer to say "executive ability" or "administrative ability."

This ideal, every man at the task for which he is best fitted or trained and for which he has greatest abilities, is seldom possible of realization in farming. A good test of executive ability is shown by the ability to so organize men and materials that work runs smoothly and everything is producing at the optimum. Few farmers have a chance to show this ability on the scale needed for management of large industrial plants since there are few farms where they could use this ability to full capacity, although some day the nation may have large "chain farms" or corporation farms where one man can direct the general management of many "units" which have their own foremen who work under central supervision.

Under present conditions the individual operator typically must limit the scope of his talents to the immediate farm under his management. If one may consider executive ability as a year-long resource, it is apparent that this farmer can make all the decisions for organizing his farm and for its operation, in a fraction of his available time. If he has hired workmen, they can be set at the day's tasks in a few minutes. After work starts his time may be wasted by going from one end of the farm to the other to supervise and check on the conduct of individual workmen. But the statement, "pedestrianism is a poorly paid line," still applies. Executive talent is poorly used in walking from place to place between moments of application. It is well used when centrally located where problems can come to it for decision. Horseback transportation aids somewhat; motor car transportation aids more. When the day of two-way frequency modulation radio communication has been reached, then an executive from a central point can keep in constant touch with his men over a 10- to 25-mile radius and avoid the time lost in travel, assuming that the men are employed in ways permitting them to be near a frequency modulation radio for such communications.

ADAPTATION OF CONCLUSIONS FROM ANY SPECIFIC ANALYSIS

No conclusions made by a study of conditions in one area should be applied to another area until tests have been made to determine whether they are applicable in the second area. Since the method of analysis suggested in this study are reasonably rapid in use, it would be far preferable to make separate analysis for each area, rather than to attempt to apply conclusions from one study to other areas. In the past there was some justification for such a procedure, since it saved the time necessary to make separate field studies. But with the greater speed and accuracy in analysis which are possible with this technique, this argument is no longer valid.

CONCLUSION

Progress in successfully attacking many of the farmers' problems of organization and management has been slow because the agricultural economist was forced to depend upon local opinion, observation, or averages of mass data for material to guide him. Frequently it was difficult to satisfy critical farmers that proposals were in fact improvements in method, since the farmer insisted that his farm was different.

Equations (1) to (3) give the agricultural economist a powerful tool of analysis which can be applied to the conditions on the individual farm with a high degree of confidence in the results. The farmer will see what happens from a change in production methods on his farm under the prevailing conditions. The emphasis can be placed upon ways and means to avoid unprofitable change or upon necessary changes to permit fullest use of improved technology.

This method is essentially, in its general aspects, the method of marginal analysis, in that all the changes can be analyzed as individual changes, not as average changes. Individual operations on this farm can be studied, not average results on other farms. It is important to stress the fact that only where field work is of a continuous-movement, power-drawn type can this analysis be relied upon. The equations will prove effective in analyzing seedbed preparation, seeding, cultivation and the power phases of harvest where changes in both labor and machinery costs are included in the analysis. The equations will not be reliable in those operations dependent upon manual skill and dexterity, such as weeding and thinning, hand picking or sorting. Many of these operations are on a contract basis, so that costs can be studied separately from hours.

The equations will enable one to distinguish between labor requirements under a given set of conditions, in comparison with the highest degree of efficiency under any set of conditions. This distinction will have an important national significance where information is desired about the effects of changes in farm population upon total farm production. The equations and marginal analysis will help to distinguish between national farm programs which maintain, improve or decrease the efficiency of individual farms. Such analysis will help to focus public attention upon the most effective use of national funds to secure desired objectives, furnishing concrete evidence of the effects of proposed changes.

APPENDIX

TABLE 1.—HOURS REQUIRED TO COVER 1 ACRE. NO ALLOWANCE
FOR REST OR TURNS $\frac{(8.25)}{SW}$

Width of machine		Miles travel to cover 1 acre		Speed of travel—miles per hour								
in.	ft.			1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3
12	1	8.25	8.25	6.6	5.5	4.71	4.12	3.67	3.3	3.00	2.75	
14	1 1/6	7.07	7.07	5.66	4.71	4.04	3.54	3.14	2.83	2.57	2.36	
16	1 1/3	6.19	6.19	4.95	4.12	3.54	3.09	2.75	2.48	2.25	2.06	
18	1 1/2	5.5	5.5	4.40	3.67	3.14	2.75	2.44	2.2	2.	1.83	
20	1 2/3	4.95	4.95	3.96	3.3	2.83	2.48	2.2	1.98	1.80	1.65	
22	1 5/6	4.5	4.5	3.6	3.	2.57	2.25	2.	1.8	1.64	1.5	
24	2	4.12	4.12	3.30	2.75	2.36	2.06	1.83	1.65	1.50	1.38	
26	2 1/6	3.81	3.81	3.05	2.54	2.18	1.90	1.69	1.52	1.38	1.27	
28	2 1/3	3.54	3.54	2.83	2.36	2.02	1.77	1.57	1.41	1.29	1.18	
30	2 1/5	3.3	3.3	2.64	2.2	1.89	1.65	1.47	1.32	1.2	1.1	
32	2 2/3	3.09	3.09	2.48	2.06	1.77	1.55	1.38	1.24	1.12	1.03	
34	2 5/6	2.91	2.91	2.33	1.94	1.66	1.46	1.29	1.16	1.06	.97	
36	3	2.75	2.75	2.2	1.83	1.57	1.38	1.22	1.1	1.	.92	
38	3 1/6	2.6	2.6	2.08	1.74	1.49	1.3	1.16	1.04	.95	.87	
40	3 1/3	2.48	2.48	1.98	1.65	1.41	1.24	1.1	.99	.9	.82	
42	3 1/2	2.36	2.36	1.89	1.57	1.35	1.18	1.05	.94	.86	.79	
44	3 2/3	2.25	2.25	1.8	1.5	1.29	1.12	1.	.9	.82	.75	
48	4	2.06	2.06	1.65	1.38	1.18	1.03	.92	.82	.75	.69	
52	4 1/3	1.9	1.9	1.52	1.27	1.09	.95	.85	.76	.69	.64	
54	4 1/2	1.83	1.83	1.47	1.22	1.05	.92	.82	.73	.67	.61	
56	4 2/3	1.77	1.77	1.41	1.18	1.01	.88	.79	.71	.64	.59	
60	5	1.65	1.65	1.32	1.10	.94	.82	.73	.66	.60	.55	
64	5 1/3	1.55	1.55	1.24	1.03	.88	.77	.69	.62	.56	.52	
66	5 1/2	1.5	1.5	1.2	1.	.86	.75	.67	.60	.54	.5	
68	5 2/3	1.46	1.46	1.16	.97	.83	.73	.65	.58	.53	.48	
72	6	1.38	1.38	1.1	.92	.79	.69	.61	.55	.5	.46	
76	6 1/3	1.3	1.3	1.04	.87	.74	.65	.58	.52	.47	.43	
78	6 1/2	1.27	1.27	1.02	.85	.72	.64	.56	.51	.46	.42	
80	6 2/3	1.24	1.24	.99	.82	.71	.62	.55	.50	.45	.41	
84	7	1.18	1.18	.94	.79	.67	.59	.52	.47	.43	.39	

TABLE 1.—HOURS REQUIRED TO COVER 1 ACRE (Continued)

Width of machine		Miles travel to cover 1 acre	Speed of travel—miles per hour								
in.	ft.		1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3
88	7 1/3	1.12	1.12	.9	.75	.64	.56	.5	.45	.41	.38
90	7 1/2	1.1	1.1	.88	.73	.63	.55	.49	.44	.4	.37
96	8	1.03	1.03	.82	.69	.59	.52	.46	.41	.38	.34
102	8 1/2	.97	.97	.78	.65	.55	.48	.43	.39	.35	.32
104	8 2/3	.95	.95	.76	.64	.54	.48	.42	.38	.35	.32
108	9	.92	.92	.73	.61	.52	.46	.41	.37	.33	.31
112	9 1/3	.88	.88	.71	.59	.50	.44	.39	.35	.32	.3
114	9 1/2	.87	.87	.69	.58	.5	.43	.39	.35	.32	.29
120	10	.82	.82	.66	.55	.47	.41	.37	.33	.3	.28
126	10 1/2	.79	.79	.63	.52	.45	.39	.35	.31	.29	.26
132	11	.75	.75	.6	.5	.43	.38	.33	.3	.27	.25
138	11 1/2	.72	.72	.57	.48	.41	.36	.32	.29	.26	.24
144	12	.69	.69	.55	.46	.39	.34	.31	.28	.25	.23
150	12 1/2	.66	.66	.53	.44	.38	.33	.29	.26	.24	.22
156	13	.64	.64	.51	.42	.36	.32	.28	.25	.23	.21
160	13 1/3	.62	.62	.5	.41	.35	.31	.28	.25	.22	.21
162	13 1/2	.61	.61	.49	.41	.35	.31	.27	.24	.22	.20
168	14	.59	.59	.47	.39	.34	.29	.26	.24	.21	.20
170	14 1/6	.58	.58	.47	.39	.33	.29	.26	.23	.21	.19
174	14 1/2	.57	.57	.46	.38	.32	.28	.25	.23	.21	.19
180	15	.55	.55	.44	.37	.31	.28	.24	.22	.20	.18
186	15 1/2	.53	.53	.43	.36	.30	.27	.24	.21	.19	.18
190	15 5/6	.52	.52	.42	.35	.30	.26	.23	.21	.19	.17
	16	.52	.52	.41	.34	.30	.26	.23	.21	.19	.17
	16 1/2	.5	.5	.4	.33	.29	.25	.22	.2	.18	.17
	17	.48	.48	.39	.32	.28	.24	.22	.19	.18	.16
	17 1/2	.47	.47	.38	.31	.27	.24	.21	.19	.17	.16
	18	.46	.46	.37	.30	.26	.23	.20	.18	.17	.15
	18 1/2	.45	.45	.36	.30	.26	.22	.20	.18	.16	.15
	19	.43	.43	.35	.29	.25	.22	.19	.17	.16	.14
	19 1/2	.42	.42	.34	.28	.24	.21	.19	.17	.15	.14
	20	.41	.41	.33	.28	.24	.21	.18	.16	.15	.14
	20 1/2	.40	.40	.32	.27	.23	.20	.18	.16	.15	.13
	21	.39	.39	.31	.26	.22	.20	.18	.16	.14	.13
	21 1/2	.38	.38	.31	.26	.22	.19	.17	.15	.14	.13
	22	.38	.38	.30	.25	.21	.19	.17	.15	.14	.12
	22 1/2	.37	.37	.29	.24	.21	.18	.16	.15	.13	.12
	23	.36	.36	.29	.24	.20	.18	.16	.14	.13	.12
	23 1/2	.35	.35	.28	.23	.20	.18	.16	.14	.13	.12
	24	.34	.34	.28	.23	.20	.17	.15	.14	.12	.12
	24 1/2	.34	.34	.27	.22	.19	.17	.15	.14	.12	.11
	25	.33	.33	.26	.22	.19	.16	.15	.13	.12	.11
	30	.28	.28	.22	.18	.16	.14	.12	.11	.10	.09
	35	.24	.24	.19	.16	.14	.12	.10	.09	.09	.08
	40	.21	.21	.16	.14	.12	.10	.09	.08	.08	.07
	45	.18	.18	.15	.12	.10	.09	.08	.07	.07	.06
	50	.16	.16	.13	.11	.09	.08	.07	.07	.06	.06

TABLE 1-A.—HOURS REQUIRED TO COVER 1 ACRE. NO ALLOWANCE FOR REST OR TURNS

Width of machine		Miles travel to cover 1 acre	Speed of travel—miles per hour							
			3 1/4	3 1/2	3 3/4	4	4 1/4	4 1/2	4 3/4	5
12	1	8.25	2.54	2.36	2.2	2.06	1.94	1.83	1.74	1.65
14	1 1/6	7.07	2.18	2.02	1.89	1.77	1.66	1.57	1.49	1.41
16	1 1/3	6.19	1.90	1.77	1.65	1.55	1.46	1.38	1.30	1.24
18	1 1/2	5.5	1.69	1.57	1.47	1.38	1.29	1.22	1.16	1.1
20	1 2/3	4.95	1.52	1.41	1.32	1.24	1.16	1.1	1.04	.99
22	1 5/6	4.5	1.38	1.29	1.2	1.12	1.06	1.	.95	.90
24	2	4.12	1.27	1.18	1.1	1.03	.97	.92	.87	.82
26	2 1/6	3.81	1.17	1.09	1.02	.95	.90	.85	.80	.76
28	2 1/3	3.54	1.09	1.01	.94	.88	.83	.79	.74	.71
30	2 1/2	3.3	1.02	.94	.88	.82	.78	.73	.70	.66
32	2 2/3	3.09	.95	.88	.82	.77	.73	.69	.65	.62
34	2 5/6	2.91	.90	.83	.78	.73	.68	.65	.61	.58
36	3	2.75	.85	.79	.73	.69	.65	.61	.58	.55
38	3 1/6	2.6	.80	.74	.70	.65	.61	.58	.55	.52
40	3 1/3	2.48	.76	.71	.66	.62	.58	.55	.52	.50
42	3 1/2	2.36	.72	.67	.63	.59	.56	.52	.50	.47
44	3 2/3	2.25	.69	.64	.60	.56	.53	.50	.47	.45
48	4	2.06	.63	.59	.55	.52	.48	.46	.43	.41
52	4 1/3	1.9	.59	.54	.51	.48	.45	.42	.40	.38
54	4 1/2	1.83	.56	.52	.49	.46	.43	.41	.39	.37
56	4 2/3	1.77	.54	.50	.47	.44	.42	.39	.37	.35
60	5	1.65	.51	.47	.44	.41	.39	.37	.35	.33
64	5 1/3	1.55	.48	.44	.41	.39	.36	.34	.33	.31
66	5 1/2	1.5	.46	.43	.40	.38	.35	.33	.32	.30
68	5 2/3	1.46	.45	.42	.39	.36	.34	.32	.31	.29
72	6	1.38	.42	.39	.37	.34	.32	.31	.29	.28
76	6 1/3	1.3	.40	.37	.35	.33	.31	.29	.27	.26
78	6 1/2	1.27	.39	.36	.34	.32	.30	.28	.27	.25
80	6 2/3	1.24	.38	.35	.33	.31	.29	.28	.26	.25
84	7	1.18	.36	.34	.31	.30	.28	.26	.25	.24
88	7 1/3	1.12	.35	.32	.30	.28	.26	.25	.24	.22
90	7 1/2	1.1	.34	.31	.29	.28	.26	.24	.23	.22
96	8	1.03	.32	.30	.28	.26	.24	.23	.22	.21
102	8 1/2	.97	.30	.28	.26	.24	.23	.22	.20	.19
104	8 2/3	.95	.29	.27	.25	.24	.22	.21	.20	.19
108	9	.92	.28	.26	.24	.23	.22	.20	.19	.18
112	9 1/3	.88	.27	.25	.24	.22	.21	.20	.19	.18
114	9 1/2	.87	.27	.25	.23	.22	.20	.19	.18	.17
120	10	.82	.25	.24	.22	.21	.19	.18	.17	.16
126	10 1/2	.79	.24	.22	.21	.20	.18	.18	.16	.16
132	11	.75	.23	.21	.20	.19	.18	.17	.16	.15
138	11 1/2	.72	.22	.20	.19	.18	.17	.16	.15	.14
144	12	.69	.21	.20	.18	.17	.16	.15	.14	.14
150	12 1/2	.66	.20	.19	.18	.16	.16	.15	.14	.13
156	13	.64	.20	.18	.17	.16	.15	.14	.13	.13
160	13 1/3	.62	.19	.18	.16	.16	.15	.14	.13	.12

TABLE 1-A.—HOURS REQUIRED TO COVER 1 ACRE (Continued)

Width of machine		Miles travel to cover 1 acre	Speed of travel—miles per hour							
in.	ft.		3 1/4	3 1/2	3 3/4	4	4 1/4	4 1/2	4 3/4	5
162	13 1/2	.61	.19	.18	.16	.15	.14	.14	.13	.12
168	14	.59	.18	.17	.16	.15	.14	.13	.12	.12
170	14 1/6	.58	.18	.17	.16	.15	.14	.13	.12	.12
174	14 1/2	.57	.18	.16	.15	.14	.13	.13	.12	.11
180	15	.55	.17	.16	.15	.14	.13	.12	.12	.11
186	15 1/2	.53	.16	.15	.14	.13	.12	.12	.11	.11
190	15 5/6	.52	.16	.15	.14	.13	.12	.12	.11	.10
	16	.52	.16	.15	.14	.13	.12	.12	.11	.10
	16 1/2	.50	.15	.14	.13	.12	.12	.11	.10	.10
	17	.48	.15	.14	.13	.12	.11	.11	.10	.10
	17 1/2	.47	.14	.14	.13	.12	.11	.10	.10	.09
	18	.46	.14	.13	.12	.11	.11	.10	.10	.09
	18 1/2	.45	.14	.13	.12	.11	.10	.10	.09	.09
	19	.43	.13	.12	.12	.11	.10	.10	.09	.09
	19 1/2	.42	.13	.12	.11	.11	.10	.09	.09	.08
	20	.41	.13	.12	.11	.10	.10	.09	.09	.08
	20 1/2	.40	.12	.12	.11	.10	.10	.09	.08	.08
	21	.39	.12	.11	.10	.10	.09	.09	.08	.08
	21 1/2	.38	.12	.11	.10	.10	.09	.08	.08	.08
	22	.38	.12	.11	.10	.09	.09	.08	.08	.08
	22 1/2	.37	.11	.10	.10	.09	.09	.08	.08	.07
	23	.36	.11	.10	.10	.09	.08	.08	.08	.07
	23 1/2	.35	.11	.10	.09	.09	.08	.08	.07	.07
	24	.34	.11	.10	.09	.09	.08	.08	.07	.07
	24 1/2	.34	.10	.10	.09	.08	.08	.08	.07	.07
	25	.33	.10	.09	.09	.08	.08	.07	.07	.07
	30	.28	.08	.08	.07	.07	.06	.06	.06	.06
	35	.24	.07	.07	.06	.06	.06	.05	.05	.05
	40	.21	.06	.06	.06	.05	.05	.05	.04	.04
	45	.18	.06	.05	.05	.05	.04	.04	.04	.04
	50	.16	.05	.05	.04	.04	.04	.04	.04	.03

TABLE 2.—VALUES OF $\frac{16 \text{ SN}}{3 \text{ L}}$ WHERE N IS $1/2^1$.

Length of field in rods	Speed of travel — miles per hour								
	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3
10	.2667	.3333	.4000	.4667	.5333	.6000	.6667	.7333	.8000
20	.1333	.1667	.2000	.2333	.2667	.3000	.3333	.3667	.4000
30	.0889	.1111	.1333	.1556	.1778	.2000	.2222	.2444	.2667
40	.0667	.0833	.1000	.1167	.1333	.1500	.1667	.1833	.2000
50	.0533	.0667	.0800	.0933	.1067	.1200	.1333	.1467	.1600
60	.0444	.0556	.0667	.0778	.0889	.1000	.1111	.1222	.1333
70	.0381	.0476	.0571	.0667	.0762	.0857	.0952	.1048	.1143
80	.0333	.0417	.0500	.0583	.0667	.0750	.0833	.0917	.1000
90	.0296	.0370	.0444	.0518	.0592	.0667	.0741	.0815	.0889
100	.0267	.0333	.0400	.0467	.0533	.0600	.0667	.0733	.0800
110	.0242	.0303	.0364	.0424	.0485	.0545	.0606	.0667	.0727
120	.0222	.0278	.0333	.0389	.0444	.0500	.0556	.0611	.0667
130	.0205	.0256	.0308	.0359	.0410	.0462	.0513	.0564	.0615
140	.0190	.0238	.0286	.0333	.0381	.0428	.0476	.0524	.0571
150	.0178	.0222	.0267	.0311	.0356	.0400	.0444	.0489	.0533
160	.0167	.0208	.0250	.0292	.0333	.0375	.0417	.0458	.0500
240	.0111	.0139	.0167	.0194	.0222	.0250	.0278	.0306	.0333
320	.0083	.0104	.0125	.0146	.0167	.0188	.0208	.0229	.0250

	Speed of travel—miles per hour							
	3 1/4	3 1/2	3 3/4	4	4 1/4	4 1/2	4 3/4	5
10	.8667	.9333	1.0000	1.0667	1.1333	1.2000	1.2667	1.3333
20	.4333	.4667	.5000	.5333	.5667	.6000	.6333	.6667
30	.2889	.3111	.3333	.3556	.3778	.4000	.4222	.4444
40	.2167	.2333	.2500	.2667	.2833	.3000	.3167	.3333
50	.1733	.1867	.2000	.2133	.2267	.2400	.2533	.2667
60	.1444	.1556	.1667	.1778	.1889	.2000	.2111	.2222
70	.1238	.1333	.1428	.1524	.1619	.1714	.1810	.1905
80	.1083	.1167	.1250	.1333	.1417	.1500	.1583	.1667
90	.0963	.1037	.1111	.1185	.1259	.1333	.1407	.1481
100	.0867	.0933	.1000	.1067	.1133	.1200	.1267	.1333
110	.0788	.0848	.0909	.0970	.1030	.1091	.1152	.1212
120	.0722	.0778	.0833	.0889	.0944	.1000	.1056	.1111
130	.0667	.0718	.0769	.0820	.0872	.0923	.0974	.1026
140	.0619	.0667	.0714	.0762	.0810	.0857	.0905	.0952
150	.0578	.0622	.0667	.0711	.0756	.0800	.0844	.0889
160	.0542	.0583	.0625	.0667	.0708	.0750	.0792	.0833
240	.0361	.0389	.0417	.0444	.0472	.0500	.0528	.0556
320	.0271	.0292	.0312	.0333	.0354	.0375	.0396	.0417

¹ If N is $1/4$ minute the value shown in table 2 of the appendix should be reduced by one half. If N is $3/4$ minute these values should be increased by one half, while N of 1 minute would require that the value in table 2 be doubled.

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